AD NUMBER	
AD243159	
NEW LIMITATION CHANGE	

TO
Approved for public release, distribution unlimited

FROM
Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JUN 1960. Other requests shall be referred to Wright Air Development Center, Wright-Patterson AFB, OH 45433.

AUTHORITY

AFSC ltr, 4 Jun 1968

DECELERATOR BAG STUDY

Stephen L. Tomcsak

The Goodyear Tire & Rubber Company
Akron, Ohio
Special Products Development Department

JUNE 1960

WRIGHT AIR DEVELOPMENT DIVISION

DECELERATOR BAG STUDY

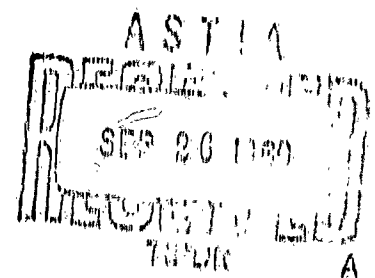*Stephen L. Tomcsak*

The Goodyear Tire & Rubber Company
Akron, Ohio
Special Products Development Department

JUNE 1960

Aeronautical Accessories Laboratory
Contract No. AF 33(600)-30825

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD
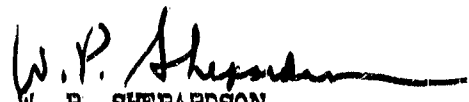
ABSTRACT

An attempt to improve the efficiency of airbag decelerators leads to a thorough study and analysis of the present barrel-shaped bags. An evaluation of these bags and airbag decelerator requirements results in a new cylindrical-shaped bag. Methods of pressure metering are discussed and a new, highly promising variable-diameter orifice is incorporated into the cylindrical bag. An evaluation of the data obtained from drop tests of the new bags indicates that the efficiency has been increased considerably over that of previous airbags.

WADC TR 59-775

iii

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

WADC TR 59-775

LIST OF TABLES

WADC TR 59-775

LIST OF SYMBOLS AND DEFINITIONS

A_c Area of contact between bag and platform . . . . . ft^2

A_m Mean area of bag . . . . ft^2

A_o Area of orifice . . . . ft^2

a Platform acceleration (vertical) . . . . ft/sec^2

a_n Platform acceleration (horizontal) . . . . ft/sec^2

a_v Subscript for average value . . . .

b Subscript pertaining to bag . . . .

D_o Orifice diameter . . . . inches

E_o Kinetic energy of platform at point of bag contact   ft #
with ground

F_ξ Net force on platform by bag . . . . pounds

g Acceleration of gravity . . . .

G Multiplier of weight or g. . . . .

G_b Bag reaction in terms of "G" units equal to bag. .
reaction/weight of platform

G_a Platform deceleration in terms of "G" units. . . .
$G = a/g$

h_f Bag height . . . . ft

h_i Bag height . . . . inches

η Efficiency - avg/max . . . .

P Bag pressure above atmospheric . . . . $\#/in^2$

P_o Bag pressure at point of orifice opening . . . . . psig

p As subscript pertaining to platform . . . .

R_b Bag reaction . . . .   pounds

R_g Ground reaction . . . .   pounds

S_f Distance to stop platform . . . .   feet

S_1 Distance to stop platform . . . .   inches

S_g Distance of platform penetrates ground . . . . . .   feet

t   Time . . . .   seconds

V   Bag volume . . . . ft^3

v   Platform velocity (vertical) . . . .   ft/sec

v_h Platform velocity (horizontal) . . . .   ft/sec

w   Weight of air in bag . . . .   pounds

W   Weight of platform per bag . . . .   pounds

W_k Work . . . .
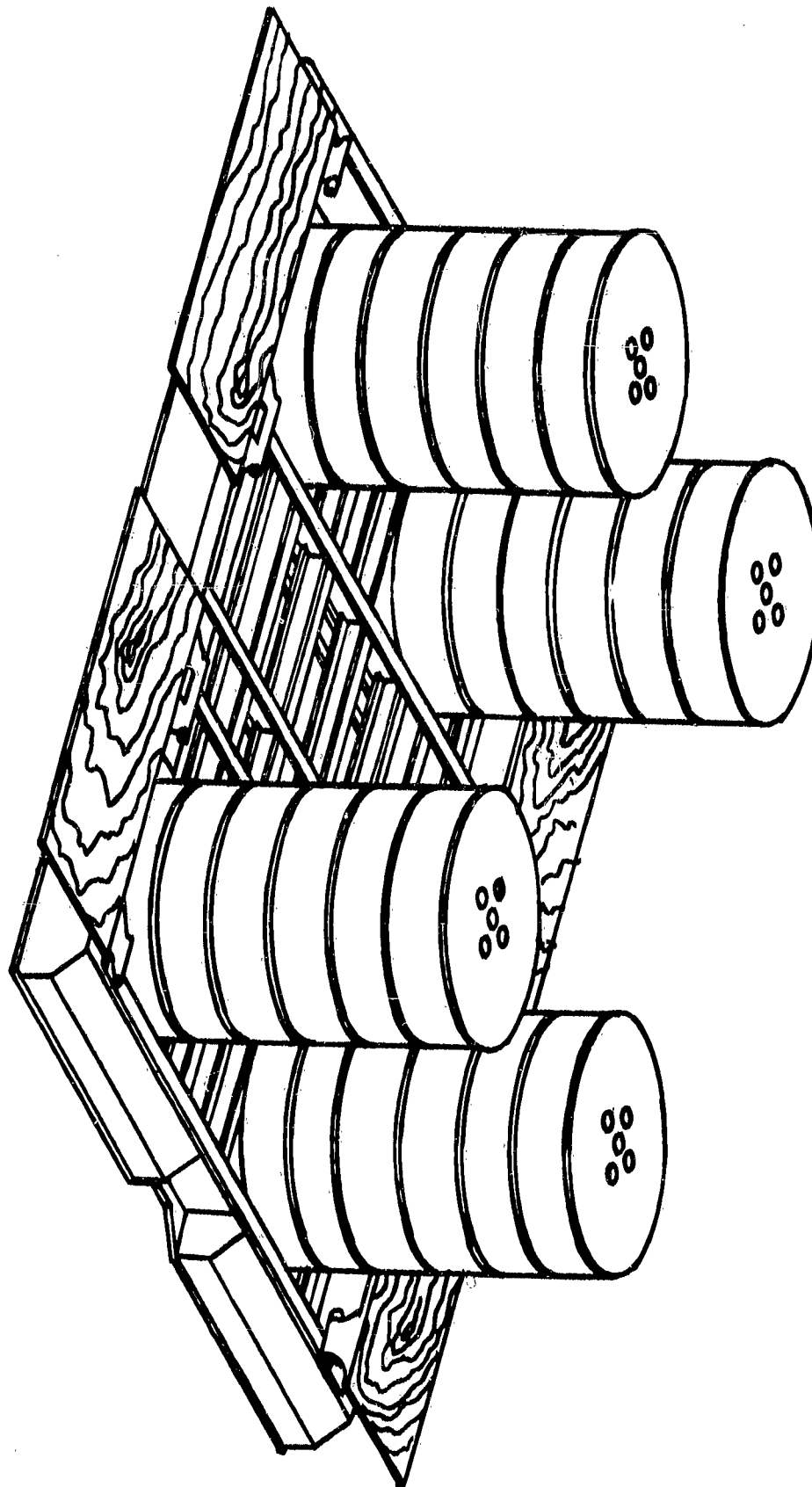
TYPICAL AIR BAG INSTALLATION ON
AERIAL DELIVERY PLATFORM

I. INTRODUCTION

A load carrying platform descending via parachute must be brought to rest upon ground contact without too great a deceleration and without excessive bouncing.

The airbags, contained in the platform, must be capable of absorbing all deceleration forces without rebound in excess of 12 g encountered in making ground contact at a vertical velocity of 30 f.p.s. and a horizontal velocity of up to 51 f.p.s. The materials used in the airbags require operation of the units throughout the temperature range of -40°F to ≠ 160°F. Although the airbags were never tested to these extremes of velocities, actual air drop tests were accomplished at vertical velocities of 30 f.p.s. combined with horizontal velocities of 32 f.p.s.

To satisfy the objectives, the study has been broken down into two primary divisions as follows:

1. The design and development of present decelerators.

   In this phase of the study the design and development of the present airbag decelerator is investigated, utilising available data specified in Technical Memorandum Report WOLE-54-55, Technical Notes WOLE-53-147 and WOLE-54-11, Lockheed Aircraft Corporation Report ER546 Gelac C.3, and Stanley Aviation Corporation Reports 43 and 119, to establish basic theories applicable to this configuration and to obtain clearly defined engineering design criteria capable of predicting performance of the end item.

2. New configurations and methods of pressure metering.

   New configurations and methods of pressure metering are investigated to establish basic theories and engineering design data for an optimum pneumatic decelerator configuration. The retardation cycle is studied from the data compiled to determine the optimum airbag decelerator configuration compatible with current requirements, and to establish theory and design data for a new configuration for various applied loads and ground impact velocities. The following conditions are considered:

   a. The influence of bag configuration on pressure metering.
   b. Investigating partitioned bag employing various sizes of orifice between inner cells.
   c. Investigating suitable orifice metering devices.
   d. Influence of bag configuration on platform toppling.
   e. Efficiency of bag configuration when displaced or rotated from normal extended position due to horizontal travel of the platform during the retardation cycle.

A discussion of the mechanics involved follows together with a theoretical analysis of the present airbag decelerator.

Energy summations:

Energy input by platform = Bag work and ground work

$$\frac{WS_o^2}{2g} + WS = R_{b\text{-}av} \times S + R_{g\text{-}av} \times S_g \quad \text{- - - - - - - - - - - - - (1)}$$

Assuming that the platform is stopped before striking the ground the last term can be neglected.

Solving for the stroke necessary to stop the platform:

$$S = \frac{1}{\frac{V_o^2}{2g}\left[\frac{R_{b\text{-}av}}{W} - 1\right]} \quad \text{- - - - - - - - - - - - - - - - - -(2)}$$

But $\quad \frac{R_b}{W} = G_b \quad$ by definition

Therefore $\quad S = \frac{1}{\frac{V_o^2}{2g}\left[G_{b\text{-}av} - 1\right]} \quad \text{- - - - - - - - - - - - -(3)}$

Defining $G_{b\text{-}av} = \eta \times G_{b\text{-}max} \quad$ (where η is the airbag efficiency), the stroke becomes

$$S = \frac{1}{\frac{V^2}{2g}\left[\eta \, G_{b\text{-}max} - 1\right]} \quad \text{- - - - - - - - - - - - - - - - - (4)}$$

To determine the relationship between bag reaction and platform deceleration the force equation $F = ma$ is used.

$$F = R_b - W = \frac{W}{g}\frac{dv}{dt} = \frac{Wa}{g} = WG_a \quad \text{- - - - - - - - - - - - -(5)}$$

Where $G_a = \frac{a}{g}$, the platform deceleration in "G" units.

Transposing in equation (5) and substituting G_b for $\frac{R_b}{W}$

$$G_b = Ga \neq 1 \text{ --------------------------- (6)}$$

which means that the deceleration force on the platform in "Gs" is one unit less than the bag reaction in "Gs" for the vertical component.

Equation (4) indicates that the stroke required to stop the platform is dependent on ground contact velocity, the maximum allowable bag reaction, and the average level of this reaction through the b_{ag} compression stroke. It therefore follows that the factors which affect the shape of the bag reaction curve must be investigated.

Pressure and Reaction History:

Bag reaction is related to bag pressure through the contact area between bag and platform in the case of a flat contact area where the platform area is larger than the bag contact area.

In equation form we can then write the following expressions:

$$R_b = PxA_o \text{ ---------------------------- (7)}$$

$$G_b = \frac{PxA_o}{W} \text{ ------------------------- (8)}$$

$$Ga = G_b - 1 = \frac{PxAo}{W} - 1 \text{ ----------------- (9)}$$

For future reference we also write the following expressions of work:

$$W_{kb} = \int_{s_1}^{s2} R_b \, ds \text{ ------------------- (10)}$$

$$W_{kp} = \frac{Wv^2}{2g} \neq WS \text{ -------------------- (11)}$$

$$R_{b-av} = \frac{W_{kb}}{S} \text{ ---------------------- (12)}$$

To determine the history of the pressure and reaction curves, the method of calculation used is derived using basic force equations in a step integration procedure for small time increments.

The steps are as follows:

For the case with no air loss from the bag and assuming adiabatic compression:

1) Change in stroke $\Delta S = V \cdot \Delta t$

2) At the end of the time increment Δt, the new stroke $= S = S_0 + \Delta S$

3) The bag volume at this stroke is determined by equation or graphical methods.

4) With the new bag volume the bag pressure is calculated:

$$P = \text{Constant} \left[\frac{W}{V_b} \right]^{1.4} - P\text{atmospheric}$$

5) The average pressure over the Δt time increment is obtained

6) The area at the end of the time increment is used to obtain the average contact area between bag and platform.

7) Average bag reaction $R_{av} = P_{av} \times Ac$

8) The net force F_{Σ} acting to decelerate the platform $F = W - R_{av}$ is obtained.

9) The average velocity change then $\Delta V = \dfrac{F \; \Delta t \cdot g}{W}$

10) Adding this ΔV to the initial velocity gives the new velocity at the end of the time increment.

11) The next cycle of computations can then be started.

For the case with air loss through an orifice the same steps are used up through (6) of the preceding. It is then necessary to determine air flow.

The general equation for flow through an orifice is:

$$W = C_D \cdot P_2 \cdot 2.05 A_2 \left[\frac{\left(\dfrac{P_1}{P_2}\right)^{.283} \left(\dfrac{P_1}{P_2}\right)^{.283} - 1}{P_1 V_b} \; WR \right]^{\frac{1}{2}}$$

Where the coefficient of discharge is a variable depending on the ratio of the pressure differential between the upstream and downstream pressures. From experimental work on orifice flow the expression for C_D can be evolved as:

$$C_D = .875 + .145 \left(\frac{P_2}{P_1}\right) - 1.03 \left(\frac{P_2}{P_1}\right)^2 + 0.62 \left(\frac{P_2}{P_1}\right)^3$$

The combination of these two equations is plotted and presented in Figure 1.

7) With the chart of flow weight vs. bag pressure and a given orifice area, the amount of air escaping can be determined for an increment of time.

WADC TR 59-775

8) Subtract the weight of escaped air from the original weight of air at the beginning of the time increment.

9) With the new air weight in the bag, a new pressure can be found as plotted in Figure 3.

10) The pressure averaged out for the time increment will allow for obtaining an average reaction as in the preceding procedure and the calculations can be carried on in the same manner as before.

From the above calculation procedures the only remaining unknowns are the rate of change of contact area and bag volume with respect to stroke.

The contact area of the bag is somewhat greater than the actual cross sectional area at a given position of stroke. For the nominal bag size chosen to calculate from, this area, with the stroke as the variable, is expressed as:

$$A_c = 3.14 + 0.212 \, S_1 - 0.0026 \, S_1^{\,2}$$

and the volume therefore becomes:

$$V_b = 18.82 - 0.262 \, S_1 - 0.00892 \, S_1^{\,2} + 0.0000732 \, S_1^{\,3}$$

where the S_1 is stroke in inches. The volume and contact area curve is enclosed for a 24" x 34" x 38" bag (Figure 2).

Mean area versus Orifice Diameter

Dependent on the cross sectional area of the bag, the rate of air compression is greater for larger areas and less for smaller areas.

To limit pressure peaks and maximum G loadings then, and to maintain similar pressure curves for different bag sizes, the orifice diameter should be varied directly vs. bag diameters.

Thus, the ratio of Am/Ao is constant and establishing an optimum orifice for one bag size will then show how the orifice diameter must be changed to meet optimum performance for different bag sizes.

Stroke and Bag Height

From analyzing the theoretical bag performance curves it has been concluded that the efficiency of the retardation cycle for optimum conditions is approximately constant. This means that the stroke can be considered as a function of input velocity and maximum G loading.

But as will be shown, the maximum G loading is a function of input velocity, bag area, bag height and orifice area. Equation (4) can be rewritten as:

$$S = f_1 \left[\frac{V^2}{2g \, G \, max} \right] \quad \text{-------------------(4a)}$$

$$\text{but} \quad G \, max = f_2 \left[\frac{V^2 \, Am}{2g \, h \, A_o} \right] \quad \text{-----------------(13)}$$

$$\text{then} \quad S = f_3 \left[h_1 \, \frac{Ao}{Am} \right] \quad \text{-------------------(14)}$$

The bag height must be greater than the required stroke to insure sufficient platform retardation before ground impact and to take into consideration input variation and ground irregularities some additional stroke must be allowed for. It appears reasonable to add approximately 4" to the bag height to account for these variables.

Onto this must be added the packaging depth of the platform which is approximately another 4", so that the final bag height will be 8" greater than the theoretical stroke required.

It is then seen that equation (14) will show that the stroke is dependent on the orifice area, the mean area of the bag, and the bag height. The bag area is fixed by the size of the platform, and this in turn determines the bag height.

Since for optimum performance the orifice area is determined by the mean area of the bag, equation (14) resolves into:

$$S = f_4 (A_o) \text{ -------------------------------------(14a)}$$

The approximation can then be made that the stroke for optimum performance will be essentially constant, if the orifice diameter is constant.

Maximum bag height in the case of horizontal velocity components becomes a critical point. With a high horizontal component of velocity the platform will move from above the supporting bags, besides causing toppling forces, this will mean that the bags could be rolled out from under the platform before the platform comes to rest vertically or approaches the ground close enough for impact from a reasonable drop height.

The correlation between bag height and allowable horizontal velocity can be obtained by drop tests.

Bag Diameter

Bag diameter is governed by three considerations:

1) Rate of volume change versus stroke.
2) Bag stability as described by the ratio of height/diameter.
3) Available packaging size as designated by the platform design.

The rate of volume changes affects the pressure build-up and deceleration build-up. The rate of these build-ups and their peak values are dependent on the relief area of the orifice.

With a large bag area the orifice opening must be increased to limit the peak pressures and deceleration loads. However, increasing the orifice diameter would involve an increase in stroke. The solution of bag diameter becomes a trial-and-error problem with the top limit being set by Item 3 above.

Bag stability for single bag operation would have to be considered. However, with the use of a multiple bag arrangement this factor is not as important.

Discussion of Performance Curves

For design purposes consideration must be given initially to the maximum decelerations and pressures occurring during the compression cycle.

Maximum Deceleration

The platform and its load are restricted to upper limits depending on their vulnerability to high accelerations. The upper limit for this investigation has been set at 13 "G", which means the platform is allowed a deceleration in the vertical direction of $13 \times 32.2 = 418.6$ ft/sec/sec. This means that the bag reaction (from equation 6) can reach a value of 14 times the weight of the load and platform for vertical deceleration.

The maximum bag reactions for a range of input conditions have been plotted against the dimensionless parameter $V_o^2 V / 2_g h^2 A_o$ resulting in a series of points approximating a straight line. (Figure 4).

These points were obtained from the theoretical performance curves where the values in the dimensionless parameter were the main factors influencing the maximum bag reaction. With values out of the range of optimum performance the resulting peak reactions were not always within the range of the mean curve drawn. This means that use of this "G" maximum curve is predicated on "reasonable" conditions of operation which will ultimately result in optimum bag performance.

The equation of this curve can be written as:

$$G_b.max = 1 + .093 \frac{V_o^2 V}{2_{gh}{}^2 A_o} + .5 \ ----------- \ (15)$$

where V_o is the platform velocity at the time of bag contact with the ground.

Maximum Pressure

Consideration must be given to the maximum pressure developed in the bag from the standpoint of bag design. There are conditions of high platform weights where the deceleration limits are not a governing factor but where the bag pressures may be excessive.

$$\text{By example, bag reaction} = PA_o$$

$$G_a.max = 13 \ ; \quad \therefore \ G_b.max = 14$$

For a 2000# load this means the allowable bag reaction is 28,000 pounds. However, if the contact area at this peak reaction is 7 ft^2 the bag pressure would be 27.8 psig, showing that low decelerations do not necessarily mean low bag pressures. In this case normal bag design would not allow a 27.8 psig pressure and the design limit would be based on peak pressure rather than peak deceleration. Thus peak bag pressure must be considered.

By the same method as used in developing the parameter for maximum bag reaction, the maximum pressure parameter was obtained (Figure 4). The equation for this curve can be written as:

$$P.max = 5.6 \times 10^{-4} \frac{E_o}{A_o h} + .5 \ ------------- \ (16)$$

Orifice Size

The size of the orifice besides being a variable in the pressure and deceleration parameters is tied into the bag design from the standpoint of optimum performance.

By optimum performance is meant the most satisfactory deceleration history of the load platform. A satisfactory history will result in the platform being stopped without bounce or high velocity impact with the ground.

Bounce is a result of bringing the platform to vertical rest while there is still a net upward force from the bag due to airbag pressure. To prevent bouncing it is not essential to reduce bag pressure to atmospheric; however, the bag reaction must be no greater than the weight of the load and platform. With an orifice that is too small a relatively slow rate of air escape will ensue, which, besides causing a high pressure and deceleration build-up, will mean that there will still be considerable bag reaction when the platform comes to vertical rest.

The high pressures will stop the platform sooner than required (platform being relatively high off the ground when stopped) and the high "residual reaction" will then bounce the platform upward.

The opposite extreme of too large an orifice will result in a relatively low reaction through the cycle since a fast air escape in relation to bag compression will not allow a pressure build-up.

This means that the platform would not be slowed sufficiently prior to ground contact, resulting in an impact shock. See Figure 5 which shows the effect of varying orifice size.

In between these two orifice limits is a range of sizes which would result in optimum performance. That is the platform would be brought to a zero or low velocity which would not cause impact shocks and at the same time the proper orifice size would have allowed sufficient air escape so that the bag reaction would be too low to cause excessive bounce.

Once this optimum size is established for a given bag diameter by trying out different orifice sizes it follows that optimum performance for other bag diameters can be predicted by direct relation:

That is: $\dfrac{Ao-1}{Am-1} = \dfrac{Ao-2}{Am-2}$

The orifice size has been assumed to be constant for this initial investigation.

Correlation:

WADC drop tests as shown in technical reports WCLE 53-147 and 54-11 indicate that the decelerator bags used were not opened fully prior to ground contact.

Figure 6 through Figure 18 were made up from data presented in these reports. It is noted that the pressure and deceleration curves rarely start their rise at the instant of bag contact with the ground (zero stroke). This is indicative of incomplete bag extension.

In such a case correlation with computed values is unreliable in that pressure and deceleration peaks are dependent on bag height and volume. Referring to equations 15 and 16:

$$G_b . Max = f_1 \left[\frac{V\gamma^2}{2gh^2 \, A_0} \right] \quad \text{---------------} \quad (15a)$$

$$P \, max = f_2 \left[\frac{E_0}{A_c \gamma} \right] \quad \text{---------------} \quad (16a)$$

where the volume V and bag height h are the values obtained with the bag fully open. If the bag is not fully extended then the smaller height changes the pressure and reaction histories by changing the initial point of start for the air compression.

Figure 6 through Figure 18 show that the bag height was not constant for the WADC drop tests. Since the maximum decelerations and pressures are dependent on this height, there is relatively poor correlation between actual and predicted performance.

It can be shown from equation 13 that G max is a function of the square of the height:

$$G \, max = f_1 \left[\frac{V^2}{2gh} \cdot \frac{A_m}{A_0} \right] \quad \text{---------------} \quad (13)$$

$$\therefore \frac{dG \, max}{dh} = \frac{d}{dh} \left[f_1 \left(\frac{V^2}{2gh} \cdot \frac{A_m}{A_0} \right) \right] = f_5 \left(\frac{1}{h^2} \right)$$

This shows that a slight discrepancy in bag height makes correlation with actual tests difficult.

By the same token, it is evident that this factor of bag extension is critical and for actual drops, if the bag extension cannot be governed closely, a wide variation in "G" loading can be expected.

Since the peak pressures are affected by the bag height to the first power rather than the square, it would be expected that correlation between computed and actual pressures would be better than the "G" load correlation. The correlation chart of maximum pressures and "G" loads (Figure 4) shows this to be the case.

Drop tests in Figure 19 show the same general correlation.

Bag Design:

The parameter charts of peak pressure and bag reaction are used to determine the general height and diameter of a proposed bag. See Figure 5.

The required orifice size for optimum performance can be selected from the mean area vs. D_0 curve of Figure 5.

The given and allowable conditions of performance must be known. From the load being carried, a maximum allowable deceleration may be given. The input or terminal parachute velocity must be known.

WADC TR 59-775

From bag manufacturing standpoint, a maximum allowable pressure is determined, and from the platform being used a maximum bag diameter may be given.

The design procedure is one of trial and error normally, where a nominal bag configuration is tried and, if not satisfactory, modified to give allowable pressure and deceleration peaks.

It is found that maximum platform velocities and weights will define the maximum bag height required from a maximum allowable pressure standpoint. That is, bag pressure is the design criterion for maximum weight and velocity. On it depends the final height of the bag to limit peak pressures.

To determine the minimum allowable bag height, when designing where peak decelerations are the criteria and low weights are involved, the primary concern is the input velocity.

An example for bag design follows:

Given: Maximum allowable deceleration of 419 ft/sec^2, with a platform weight per bag of 2500# and an allowable pressure peak of 20 psig. Terminal parachute velocity in 30 ft/sec.

Find the proper bag height, diameter and orifice size:

$$G_a = \frac{419}{32.2} = 13$$

$$G_b = G_a \neq 1 = 14$$

Assume an average bag area of 6 ft^2. Then from Figure 5:

$$D_o = 6 \quad ; \quad Ao = \frac{1}{5.1}$$

Designing to peak pressure: From Figure 5 maximum allowable value for

$$\frac{Eo}{Aoh} = 35,400. \quad \text{Then solving for bag height;} \quad h = \frac{Eo \times 12}{Ao \times 35,400}$$

$$h = 60.5"$$

Designing to peak deceleration: From Figure 5 maximum allowable value for

$$\frac{V^2}{2gh^2 Ao} = 140.$$

Then solving for bag height; $h = \left(\frac{V}{h}\right) \frac{V^2}{2g \, Ao \, 140} = 36.7"$

This shows that pressure is the criterion for bag height and that a 60" bag would be required with the assumed mean area of 6 ft^2.

This height appears too great particularly in that it is not a good balance for the required height of deceleration design. To decrease the height a second trial is made using a 7" diameter orifice. This requires a mean area (from Fig 5) of 8 ft^2.

Using the same method as previously:

$$h = 60.5 \times \frac{36}{49} = 44.5" \text{ -- -- -- -- -- -- -- -- -- -- Pressure criterion}$$

$$h = 36.7 \times \frac{8}{6} \times \frac{36}{49} = 36" \text{ -- -- -- -- -- -- -- -- -- Deceleration criterion}$$

This appears to be a better balance of required heights and is in general agreement with results of drop tests run in previous tests. Precautionary design indicates that the bag height should be increased some above the calculated 44.5" since it has been seen that there is usually a loss in bag height due to incomplete bag extension.

Bag Design - Loading Range:

The present drawings cover two bag heights, a 40" bag and a 50" bag. From the standpoint of obtaining a large range of platform loadings it has been concluded that the 50" bag is more suited, since it will take higher loadings than the 40" bag.

A bag with an initial volume of approximately 25 cubic feet and height of 50", theoretically will handle up to 2800# with ground contact velocities of 30 ft/sec. This would utilize a 7" orifice and allow for a 20 psig peak pressure.

Example: From the pressure parameter chart:

$$\frac{Eo}{Aoh} = 35,500 \text{ for } P_{max} = 20$$

but $\dfrac{Eo}{Aoh} = \dfrac{3.74}{4.166} = 0.8975 \, Eo$

from substituting values of Ao and h.

Equating: $35,500 = .8975 \, Eo$

$$Eo = 39,600 \text{ maximum allowable}$$

then for contact velocity of 30'/s

$$W = \frac{Eo \times 2g}{900} = 2830\#$$

It has been previously noted that the full bag height is normally not utilized and the maximum loading per bag is recommended as 2500#.

With this same bag, used with minimum values of weight, the weight could be brought to rest sooner. However, this would mean a considerable "residual" stroke remaining. It is therefore concluded that though the platform weights be lessened, the orifice size should remain the same.

An 800# weight at 30 ft/sec will take up 34" of stroke before reaching its minimum velocity. After this it will gain velocity slowly since very little bag reaction (and thus pressure) is needed to resist the 800# weight.

The minimum value of the loading range will be governed in the final analysis by the component of horizontal velocity of wind. For the lighter weights the time of the stroke cycle will be longer since the deceleration values are lower, and this will allow for more horizontal travel than with shorter times.

It is recommended then that the minimum weights be finalized after horizontal drop tests are concluded.

WADC TR 59-775

III. RECOMMENDED BAG DESIGN

Configuration: Since the barrel shaped bag is already through the design stage and has been tested in drops, it is recommended that a cylindrical bag be tested.

It is felt that a cylindrical bag will have no disadvantages with respect to the barrel, and will have the advantages of simplicity and more complete volume opening. A more complete discussion of the relative merits of the two configurations will be given later in this report.

For more efficient performance the ideal would be to allow for a constant pressure throughout the cycle. As outlined in a Aerojet Report * a constant pressure relief valve suitable for use in this type of a deceleration cycle becomes a complex unit. Its precision and weight would bag its use in the light of the aims of Exhibit WCLEH-1-44.

The other possible methods of approaching a flat pressure curve are described below:

1) **Variable Diameter:**

   As described in the Aerojet Report, a variable diameter orifice would tend to approach a flat pressure curve. The main detrimental feature, however, is that the orifice has at all times an opening to the atmosphere. This is a relatively simple matter to correct with a bung-like plug which could be easily installed and would be blown out in the initial phase of the compression stroke.

   The main design items on this orifice would be to establish the range of diameters needed to accomplish optimum performance, and the variation of diameter to bag pressure.

2) **Two Phase Cycle:**

   A second orifice, consisting of simply a fabric disc with a hole cut out in its center could be hung inside the bag in a predetermined position. Its hole size would be smaller than the main orifice of the bag. Dependent on its location in the bag, it would cover the large main orifice at a predetermined point of bag stroke, thus decreasing the air escape rate. This would cause an increase in the pressure rise of the bag to give prolonged bag reaction at the latter end of the stroke.

   This second orifice would be brought into play after the bag pressure had begun to drop. Bag toppling due to horizontal movement, however, may not allow the proper working of this method.

Air Bag Construction

Several cylindrical type airbags with the variable diameter orifice were constructed for test purposes. The finalized variable diameter orifice and blow-out bung is shown incorporated in the airbag of Figure 94. This variable diameter orifice has been developed to a degree in which, though not producing a flat pressure history curve, does tend to flatten the curve.

- - - - - - - - -

* Contract AF 33(038)3358, Project XM-1079, E.O. No. 539-44.

This orifice has been used in test drops in conjunction with another program and its leveling action has been confirmed. No tests to date have been made to compare the variation due to design size change of this orifice. However, it is recommended that this variable diameter principle be incorporated and several variation on its basic design dimensions be tested.

Attachment collar design has been changed so that an intermediate collar will be used. This collar is laced to the platform initially and will normally remain fixed to the platform through the nylon lacing. It will have snap-type fasteners on it which will accept opposite fasteners on the collar of the bag proper. During landing, the bag will strip away from the intermediate collar in cross wind drops.

Test Recommendations

It is anticipated that, although drop tests under free-fall conditions do not exactly duplicate the constant velocity descent of parachute deliver, drop tests will still be a criterion for comparison purposes.

From the design study the main variables are weight, impact velocity, orifice area, and useful bag height. It is proposed that these variables be introduced into tests to establish correlation with theoretical parameters.

To obtain reliable results, two methods of measuring the drop histories are recommended:

1) Instrumentation to record acceleration and pressure versus time by oscillographic techniques.

2) Hi-speed camera coverage with timing the distance references. The results from the two methods of measuring can be compared for better interpretation should there be some question of instrumentation.

Proposed Test Schedule

Three drops of each condition are recommended to obtain an average result. Initial tests would be to determine the optimum orifice diameter and the remaining tests would be using this diameter.

Following is a tabulation of the proposed schedule:

Run	No. of Tests	W/bag	V_0	h	D_o	θ	Remarks
1	3	1400	27	50	5	90)	To determine orifice function
2	3	1400	27	50	6	90)	
3	3	1400	27	50	7	90)	
4	3	800	27	50	6	90)	To determine weight function
5	3	2000	27	50	6	90)	
6	3	1400	24	50	6	90)	To determine velocity function
7	3	1400	30	50	6	90)	

Run	No. of Tests	W/bag	V_o	h	D_o	θ	Remarks
8	3	1400	27	42	6	90)	To determine height
9	3	1400	27	42	6	90)	function
10	3	1400	30	50	6	31°)	To determine effect
11	3	1400	30	50	6	60°)	of angular descent

Depending on the results of these tests, additional drops may have to be run varying angular descent and velocity.

Acceleration instrumentation should be fixed directly to the platform at its center of gravity (or center of bag reaction) as well as at two other points away from the first accelerometer so that a summation of maximum accelerations can be obtained.

Initial tests with horizontal velocity components may be instrumented to check horizontal accelerations to see whether these values are critical from a stress standpoint.

Test Procedure

Two series of drop tests were conducted. One series covered a range of vertical impact velocities and loadings for a single airbag, and the other series covered a system of four airbag per platform.

Each drop test was rigged to incorporate a pressure pick-up device which was inserted into the bag to record the history of the pressure curve in the airbag during compression. Three accelerometers were located as near to the center of gravity as possible on the load system to record the decelerations in the X, Y, and Z axis during compression of the airbag. A multi-channel oscillograph instrument permanently recorded the pressure and deceleration. A high-speed camera was used on the majority of the tests to compare and ascertain results of instrumentations.

The arrangement for the test set-up is depicted in the sketches of Figures 21, 22 and 95.

In the single bag drop series, the top surface of an airbag was attached by cord to the underside of the platform of known weight and hoisted to a predetermined height. A quick release type of hook released the platform at which time the instrumentations and movie camera began recording.

Essentially, the multi-bag test series were conducted in the same manner as the single airbag series, except a pressure pick-up cell was included in each of the four airbags to record individual pressure curves.

In each of the series of drop tests performed, the intent was to determine the function of the airbag due to the variance of the variable orifice and plug diameters, weight of platform, bag height, and impact velocities. The data obtained for the various conditions is submitted in graph form, which was recharted from the recording oscillograph to depict deceleration versus time and pressure versus time. See Figures 32 through 92.

Tables I and II are a tabulation of the data received from the instrumentation and movies of the drop test. In these series of drop tests only vertical impact velocities were performed since the test facilities available at the testing site were not suitable to handle horizontal velocity conditions.

Discussion of Results

A total of 14 single bag tests and 21 multi-bag tests were conducted; however, to eliminate repetition, only 3 single bag tests and 11 multi-bag tests are submitted in this report.

Throughout the performance of the tests, only minor damages were incurred by the test bags. One airbag was ripped in a descent caused by the pressure pick-up tubes, that were inserted into the bag, puncturing the fabric. Some fabric taping covering the flexible cables was also loosened due to the impact during drops, which may be considered minor, since a number of drops were conducted on each bag. The low mortality of the airbags proved out the reliability of the chosen material used in the construction of the airbags.

On earlier drops performed, it was noticed that aircraft cables girthing the airbags would tend to be too flexible for airbags. The bag, when extended from the bottom of the platform, would tend to collapse on the sides, which lessened the air volume in the bag and, consequently, decreased the usable stroke of the bag. Later versions of the airbag incorporated stiffer bead rings in lieu of the flexible cables, which improved the faulty deformation condition by keeping the airbag more cylindrical in shape during the drop tests.

There exists a dissimilarity between actual parachute-supported and free-fall drops in the vertical velocity of the platform and airbags. There is no acceleration during descent by a parachute-supported load since gravity attraction is counteracted at a constant value by the parachute. However, in free-fall drops, acceleration due to the force of gravity is present.

Instrumentation records of vertical deceleration and pressure versus time were clearly reproduced. However, some of the movie films on the drop tests were dark and not easily distinguishable. In viewing of the movies, it was noticed that improper test conditions existed. The bags were laced to the underside of the platform, which could have been cause for some of the bags to slant at ground contact. It can be realized that in the higher drops, especially, that the bags would tend to slant more at ground contact, when the bags were rigged unevenly, due to the "ram" pressure on the airbags. On other drops, the platform was noticed to fall at an angle. These conditions could readily be cause for the slight buckling of the airbags; which, in turn, caused the edge of the platform to hit the ground before the compression cycle was completed. The ground impact of the edges of the platform show up in the deceleration curves as high peaks, which generally last for only a short-time duration.

The test platforms used were not those specified. The net available stroke with the 45" airbags was 40" on the single bag test and 38" on the multi-bag tests. A matter of only a few inches is involved in the specified 41" usable bag height, but a difference does exist. In these drop tests, the platform is contacting the ground sooner than expected. In the latter part of the stroke cycle, we are getting more work out of the bags and if this part of the bag height cannot be used, then an undesirable deceleration due to ground impact could occur.

Retardation Cycle

Data obtained from the test instrumentation includes load deceleration curves, bag air pressure curves, and movie film records of the drops.

Bag reaction (in terms of "G" units vs. time) curves were plotted from the load deceleration curves. From these it was possible to obtain velocity curves.

The change in velocity during a small time increment is equal to the product of the deceleration and the time.

$$dv = a \, dt$$

But "a dt" is equal to the product of the area under the curve through the time increment and a constant whose value is determined by the units of the curve.

$$dv = k \times area$$

The velocity at bag ground impact (t = 0) was found from the relationship $v = gt = 32.2T$ where "T" is the time from release to initial ground impact and is obtained from the instrumentation curves.

Velocity curves were drawn for each test and were then used to obtain a stroke curve by the relationship

$$ds = v \, dt$$

or: the change in stroke is proportional to the area under the velocity curve. The stroke curves were then plotted for each test.

The work done by the bag to decelerate the load is given by equation (10).

$$dW_{kb} = \int_{s_1}^{s_2} R_b \, ds$$

But $\dfrac{R_b}{W} = G_b$ by definition, or $R_b = WG_b$, therefore,

$$dW_{kb} = \int_{s_1}^{s_2} R_b \, ds = W \int_{s_1}^{s_2} G_b \, ds$$

A graph has been drawn for each test showing the deceleration in "G's" plotted against the stroke. The value of the integral $\int_{s_1}^{s_2} G_b \, ds$ is given by the area under the "G" curve between S_2 and S_1. The work done by the bag during any portion of the stroke is given by the product of the weight of the load, the area under the "G" curve through the stroke increment and a constant whose value is determined by the units of the graph

$$dW_{kb} = kW \times area$$

Certain unavoidable errors have been introduced while compiling these curves. Measurements of the small sections of area under the curves results in some human error which is accumulative in the stroke and work curves; i.e., the stroke curve also includes the error in the velocity curve. It will be noticed that the velocity curve does not always reach zero at the end of the stroke as it should since it is obtained directly from the deceleration curve which includes the peaks due to ground contact of the platform.

It is difficult to estimate the validity of these curves. The error in the velocity curve shows that the "G" curve is not a true indication of the vertical deceleration of the platform. This can also be seen from the work curves which should show a total amount of work done which will be equal to the energy acquired by the platform during the fall; i.e., $1/2 \ mv^2 \neq$ ws. The error is believed to be introduced during the latter part of the stroke when the platform begins to topple. During this time the plane of the platform is not parallel to the ground and the accelerometers recording perpendicular to the platform do not give the true vertical deceleration. We believe, however, that the results, at least for the first 34" of stroke are sufficiently accurate for our purposes here.

The curves obtained for Test #17 of the single bag drop series, are in many respects typical of those obtained for the other tests. A sample of the calculations used to determine the velocity, stroke, and work curves is given here.

From the instrumentation records, we have the bag air pressure curve and the platform deceleration in "G" units. Since this was a free-fall test, the deceleration curve recorded - 1G from the time of release to initial bag ground impact. For our use, however, since we are interested in the bag reaction in terms of "G" units, the ordinates of the curve have been increased by one unit. Thus the deceleration of the platform and the bag reaction is considered to be zero until the time of initial ground contact.

From the instrumentation "G" curve of Test #17 we find the time from load release to initial bag ground impact to be 0.660 seconds. The initial velocity then is,

$$V_o = gt = (32.2)(.66) = 21.25 \text{ f.p.s.}$$

We have shown that the change in velocity through a time increment is given by $dv = k \ X \ A$ where "A" is the area under the deceleration curve.

We shall take time increments of .02 seconds and we must use the area as given under the "G" curve obtained by the instrumentation or for ease of measurement we may use the area for the time increment between the "bag reaction" G curve and the line $G = 1$. By inspection of the units involved on the graph and the relationship $A = Gg$ it will be seen that,

$dv = \dfrac{(.02)(32.2)A}{25}$ where "A" is the number of squares in the area.

Taking the first time increment ($0\_\_ .02$ seconds) we find that the specified area between the G curve and the line $G = 1$ lies below $G = 1$ and contains 18.3 squares.

$$\therefore \ dv = \dfrac{(.02)(32.2)}{25} \ (18.3) = 0.47$$

Since the curve for this period lies below the line $G = 1$, it indicates that the deceleration is negative or that the platform is accelerating. Thus the velocity is increasing and its value at .02 seconds is: $V = V_o \neq dv = 21.25 \neq 0.47 = 21.72$

This process is then repeated for each .02 second time increment to the end of the stroke.

The increase in velocity during the early part of the stroke is to be expected during free-fall conditions. Although the bag is exerting a decelerating force, the acceleration of the platform is still positive (though decreasing) for the first few inches of airbag stroke.

The change of stroke during a time increment is given by:

$$ds = v\ dt$$

or:

$$ds = K \times A \text{ where "A" is the area below the velocity curve through the time increment.}$$

Inspection of the graph shows that $ds = \dfrac{(.02)(2)(12)}{25} A$ where ds is in inches and "A" is the number of squares in the area.

The area for the first time increment contains 268 squares

$$\therefore ds = \frac{(.02)(2)(12)(268)}{25} = 5.15 \text{ inches}$$

This process is then repeated to the end of the stroke.

The "G" vs. stroke graph is obtained directly from the previously drawn graphs by eliminating the time parameter.

We have shown that the work done during a portion of the stroke is given by $dW_{kb} = kW \times A$ where "A" is the area below the "G" curve through the stroke increment.

The weight of the load is 1385 pounds and after determining "k" from the graph we have $dW_{kb} = \dfrac{(4)}{(12)(25)} (1385)\ A$

For the first stroke increment (0-4 inches), A = 4.5
$$\therefore dW_{kb} = \frac{(4)}{(12)(25)} (1385)(4.5) = 83 \text{ ft. lbs.}$$

This procedure is then repeated to the end of the stroke.

The movies of this test indicated as noted on Table I, that the bag was lined up straight at bag ground contact and then buckled slightly at approximately 50 percent bag compression causing one end of the platform to hit the ground first.

The graphs drawn for this test show that after bag ground impact the velocity continued to increase for .03 seconds to a maximum velocity of approximately 21.7 f.p.s. at that time 8 inches of stroke had been used and the pressure in the bag was about 5 psig, and about 15 inches of stroke had been used. A decrease in the rate of deceleration build-up can be seen here. The pressure built up to a maximum of 7.2 psig at .135 second and a deceleration is apparent here. At this time 31.5 inches of stroke had been used and the velocity was 13.7 fps. The pressure and deceleration then began to decrease until .155 seconds after 34.5 inches of stroke, the edge of the platform struck the ground and the deceleration rose sharply to a maximum of 8.5 G, then rapidly decreased. 40 inches of stroke were used in .23 seconds. The velocity error is apparent here.

All the tests for the multi-bag series had a 38" stroke except test numbers 19 and 20 which had strokes of 33" and 28" respectively. The high impact deceleration obtained for these tests indicate that the shorter stroke is not practical for the required loading range of these airbags.

The Orifice Function on Test Results

The curves obtained from the tests indicate that the initial part of the air-bag compression stroke is relatively inefficient with respect to the work done during the latter part of the stroke. This is due to failure of the pressure to build up to an effective working value during the early part of the stroke.

Figure 20 shows the effect of plug blow out pressure on the pressure curve. The theoretical constant pressure required to stop a load of 1400 pounds with an initial bag impact velocity of 30 fps is shown by the line "A". It is slightly over 7 psi. Prepressurization of a bag in an attempt to approximate this line. The pressure curve we desire without prepressurization is shown by the curve "B". The normal pressure curve obtained with the present blow curve shows a considerable decrease in the rate of pressure build-up when the orifice plug blow out occurs. This indicates that a more efficient bag will result from an increased plug blow-out pressure which will build up an effective working pressure earlier in the stroke as shown by the curve "D". This is an attempt to approximate the curve "B" more closely. It will be noticed that the peak pressure decreases as the blow-out pressure increases. This is because the bag is doing work earlier in the stroke thus decreasing the velocity and giving the air more time to escape per unit of stroke which results in a higher work output by the bag with low G peaks.

To test the validity of this conclusion the following chart was derived from Table I:

Orifice Dia.	Plug Dia.	Blow Out Press (Av)	Weight	Impact Vel (ave)	(Av) G Max	(Av) G Impact
4.5	6.	4.39	1385	25.85	6.92	12.62
5	6.5	3.33	1385	26.5	7.36	17.1
5	6.	3.08	1385	26.0	7.80	18.3
5.5	6.5	2.67	1385	26.2	8.65	18.7

The weights and average bag impact velocities are nearly equal for each type of orifice. The highest average blow-out pressure was attained using the 4.5" orifice with a 6" plug. This gave the most satisfactory results as predicted above. The average G Max and G Impact were both lower than that of the other orifice types. This means that although G Max was lower, more work was done during the stroke indicating a more even bag reaction during the stroke. It might be expected that an increased blow-out pressure would increase the tendency for the platform to topple; however, the lower G Impact indicates that the bag stability is not decreased. The chart also shows the average G Max and G Impact both increase as the blow-out pressure decreases.

Thus, the bags utilizing the 4.5" orifice with a 6" plug were the most efficient of those tested but since this type of bag had the highest blow-out pressure, we cannot conclude that this is the optimum bag configuration. It is recommended that the tests be continued to determine the optimum blow-out pressure.

Loading Range Data

Two series of tests were conducted, each covering a range of vertical impact

velocities and loadings. The first series, conducted on a single airbag, included vertical impact velocities of 21.25 fps to 31.15 fps and loadings of 1385 pounds. The second series had four airbags per platform with velocities of 23.6 fps to 32.04 fps and loadings of 1250 to 1850 pounds per airbag.

The sizes of the diaphragm orifice and plug were varied during the tests conducted. However, the majority of the tests were performed using the 6" plug with a $4\frac{1}{2}$" diameter diaphragm orifice which depicted the most satisfactory results.

A few tests in the multi-bag series exceeded the desired "G" loading, however, in most of these cases the movies indicated poor tests for various reasons as noted in Table II.

Then it may be concluded that the tests conducted with the $4\frac{1}{2}$" orifice and 6" plug which had a loading range of 1250 to 1850 pounds and impact velocities of 21-32 fps are satisfactory as borne out in the Mechanics section of this report.

Furthermore, in continuing the theoretical calculations, we find that the airbags could satisfactorily fall in the range of 800-2200 pounds with impact velocities of 21-30 fps.

Airbag Efficiency

Several methods of comparing the efficiencies of airbags during deceleration of various loads and impact velocities are of interest.

The work done by the bag to decelerate the load is given by equation (10):

$$W_{kb} = \int_{s_1}^{s_2} R_b \, ds$$

But, $\dfrac{R_b}{W} = G_b$ by definition or $R_b = WG_b$

$$\text{Therefore,} \quad W_{kb} = \int_{s_1}^{s_2} R_b \, ds = W \int_{s_1}^{s_2} G_b \, ds$$

A graph has been drawn for each test showing the deceleration in "G's" plotted against the stroke. The value of the integral $\int_{s_1}^{s_2} G_b \, ds$ is given by the area under the "G" curve on the graph between S_2 and S_1. The work done by the bag during any portion of the stroke is given by the product of the weight of the load, the area under the "G" curve through the stroke increment, and a constant whose value is determined by the units of the graph.

The work required to stop the load is given by the energy acquired by the load during the drop.

$$W_{kp} = \frac{WV_o^2}{2g} \neq WS$$

We now have one method of determining the efficiency of the bags; that is, the ratio of the work done by the bag to the work required to stop the load.

$$E_1 = \frac{W_{kb}}{W_{kp}}$$

This method, however, gives us no information regarding the maximum deceleration on the load during the stroke.

The maximum permissible deceleration on the load has been set at 13 G's. This suggests another method of comparing the bags; that is, the efficiency of the bag in stopping the load within the required limits of deceleration or, 13 divided by the number of "G's" at the peak of the deceleration curve. A glance at the deceleration curves shows that the curves all rise to a sharp peak near the end of the stroke when the platform topples or the edge strikes the ground. This condition would not be as likely to exist during a parachute drop because of the greater number of bags and the stability furnished by the parachute and platform. On many of the curves the deceleration rises to a peak due to the deceleration force exerted by the bag, then begins to decrease and then rises to a sharp peak due to contact with the ground. We, therefore, chose to ignore the peaks due to ground contact in the efficiency calculations and use what is indicated as due to the bag.

Another method used to determine the efficiency of the bag with respect to the deceleration on the load is given by the average "G" applied to the load during the stroke divided by the maximum number of "G's" on the load.

The average "G's" during the stroke was found by the relationship;

$$G_{AV} = \frac{W_{kb}}{S}\frac{12}{W}$$

This method gives some indication of how evenly the force is being applied through the duration of the stroke.

It is still desirable to find how efficiently the bag is using the stroke. The theoretical stroke required to stop the load without excessive deceleration is given by;

$$S_{TH} = \frac{V_o^2}{2\,a}$$

The efficiency of the bag is then found by;

$$E_4 = \frac{V_o^2}{\frac{2\,a}{S}} \qquad \text{Where "S" is the net available stroke}$$

The theoretical stroke found here is very small compared to the net available stroke causing the efficiency to be very low. Also, the results found here give little indication of the bags' performance since the net available stroke is always used completely; for bags having the same stroke, the only variable would be the impact velocity which would therefore determine the efficiency.

We now have 4 methods of finding the efficiency of a bag;

(1) $E_1 = \dfrac{W_{kb}}{W_{kp}}$ (2) $E_2 = \dfrac{13}{G_{max}}$

(3) $E_3 = \dfrac{G_{av}}{G_{max}}$ (4) $E_4 = \dfrac{S_{th}}{S}$

The results of these methods are given in Table III.

The values obtained for E_1 vary from 100% to 4%. The method of calculation depends upon the acceleration curves obtained during the tests and the accuracy with which the areas under the curves can be measured. The wide range of values can be attributed to distortions imposed upon the acceleration curves due to premature ground contact of the platforms. Generally speaking, however, the figures tell how effectively the bags are doing the work required to stop the platform, thereby giving some indication of the resultant velocity.

The reasons for the high values obtained for E_2 are obvious when the method of calculation and the maximum impact deceleration figures are consulted. The majority are well over 100% indicating that they were not decelerated by the bag in excess of the 13 G maximum specified.

Low values were also obtained for E_3 and E_4. The results of E_4 have been discussed and those of E_3 are obvious. The latter has little meaning other than a means of showing how evenly the force is being exerted during the stroke. Certain portions of the stroke wherein little work is being accomplished such as the initial part when the bag is compressing result in low values of E_3.

Comparison of Test Numbers 11, 12, and 13 For The Effect Of Drop Heights

Tests numbers 11, 12, and 13 were conducted with all conditions of the drop test being the same except for the drop height, which was varied.

Each of the drops had a load of 1550 pounds per bag with a system of 4 bags per platform. Test #11 was dropped from 9 ft, test #12 from 11'-5", and test #13 from a height of 14 ft.

Curves of work versus stroke for each of the three drops were plotted and super-imposed on one graph sheet (see Figure 23). It is noted that up until the bung is blown from the bag, which occurs in the neighborhood of a 16" stroke of the bag for each drop, the three curves are identical, denoting an equal amount of work being done by the bags regardless of the height from which the bags are released. This follows a general line of reasoning since up until the bung is blown out of the bag, a closed pressure system is had in the bag which will give the same amount of work done by the bag.

However, after the bung is blown from the bag, the work done by the bag varies to the extent that the highest drop will create more work done by the bag at any specific stroke point. This change can be readily seen in observing the velocity curves (see Figure 24) which depicts a steeper slope for the higher velocities after the bung is released from the bag. So that, more work is done by the bag from bung release to complete compression of the bag. Even though the curves for comparing test numbers 11, 12 and 13 looked fairly good, which would indicate successful drops, movies and test observation showed otherwise. The movies for each of the tests showed the bags to be spread-eagled on descending from the drop height which denotes the bags were not functioning at their best.

In referring to comparison test numbers 9, 11, and 16, we surmised that test number 11 did not do the work as should have been done. Therefore, it appears that tests 11, 12, and 13 were not good tests.

WADC TR 59-775

Comparison of Test Numbers 14, 15, and 21 For The Effect of Weight

Tests numbers 14, 15 and 21 were conducted with nearly equal velocities and varied weights. All other conditions were the same.

Each drop had a bag impact velocity of approximately 29.5 fps.

The platform had 4 airbags and the weights for tests 14, 15, and 21 were 1550 lbs, 1850 lbs, and 1350 lbs per bag respectively.

Work and velocity curves were again plotted and superimposed for these tests. (See Figures 25 and 26).

Test #14 with a weight of 1550 lb/bag had the highest work curve and the most rapid decrease in velocity. Test #21 with 1350 lb/bag load had lowest work curve and a residual velocity at the end of the stroke.

This bears out what has been predicted and shown from test results in other phases of this study, that is, a reasonable weight range variation has little effect on this work output of the bag as compared to the effect of variations in other conditions such as velocity.

Comparison of Test Numbers 18, 22, and 23 for the Effect of Orifice and Plug Size

Test numbers 18, 22 and 23 were conducted with similar weights and impact velocities. The orifice and plug sizes were varied.

The velocity and work curves were superimposed and plotted in Figures 27 and 28.

Test #22 had the lowest blow out pressure with a plug diameter of 6" and an orifice diameter of 5.25". This test also had the lowest work curve and the lowest rate of velocity decrease as expected.

The higher blow out pressures of test numbers 18 and 23 gave more satisfactory results on the work and velocity curves. Test number 18 with a plug diameter of 6" and an orifice diameter of 4.5" appears to give the best results.

Comparison of Static Drop With Actual Parachute Drop Test

Instrumented parachute drop tests were conducted at El Centro, California in January of 1958. Visual observation and instrumentation records indicated that Test #5 conducted on January 14, was a test with a wind velocity of 5 - 10 knots. We therefore, chose to graph this test in the same manner as the static drop tests. On comparing these with the graphs obtained for the static drops, we find considerable variations in the curves. The deceleration curve appears to be unreasonably low resulting in a small work output by the bag. This is due to the low pressure curve which seems to be characteristic of parachute drops, possibly because of the horizontal motion of the platform during the stroke. The general type of curve obtained from the parachute drops also differs from those obtained by the static drop test in the upward and downward sense of concavity at the beginning of the pressure build up. This also may be due to the horizontal motion of the platform.

The energy input of the platform is given by

$$\frac{1}{2} \frac{W}{g} V^2 + W_s = 20,220 \text{ ft lbs/bag}$$

This is the work that must be done to bring the platform to zero velocity. By integrating the G - stroke curve, we find that the work done by the bag plus that done by ground impact is approximately 10,000 ft lbs/bag. The magnitude of the difference between these two quantities leads to some doubt of the validity of the deceleration curve.

The general shape of the curve, however, is similar to those obtained from the static drops indicating some correlation between the two.

It should be noted that the velocity of the parachute drop does not increase during the first few inches of stroke as it does on the static drops. This is to be expected because the static drop has a deceleration value of - 1 G at initial acceleration. The result is a constant velocity for the first few inches of stroke until the bag builds up sufficient working pressure to exert a decelerating force.

Airbag Configuration

It was noted that a cylindrical bag was chosen for this study because the barrel shaped bag had already been thoroughly tested.

Initial investigation of airbag decelerators began with the barrel shaped bag because of the structural advantage in that the material is under less stress when pressurized. This, however, is compensated for by the reduced seam area of the cylindrical bag which is a critical area strengthwise.

It is generally believed that the cylindrical bag will have a disadvantage over the barrel shaped bag in that the stability will be reduced. It is felt that the barrel bag will have a tendency to roll under the action of an oblique impact, whereas the cylindrical shaped bag will be more likely to buckle. We must be more concerned, however, with the stability furnished to the platform by the bag than the stability of the bags themselves when attempting to compare the bags in this sense. The fact that the cylindrical bags cannot "roll" under the platform may increase the resistance to the horizontal motion of the platform and thus in some circumstances may increase the stability of the platform. It was noted from observations of parachute drops that the bags would tend to shear from the platform by unsnapping the fasteners at the points of attachment under conditions of high horizontal velocity thus enabling the platform to slide along the ground.

No attempt is made here to compare the action of the bags under horizontal motion of the platform but only to show the difficulty of making such a comparison without actual testing. Similar performance is expected from the two types of bags in actual tests because of the inherent stability of the multi-bag system.

Some of the advantages of the cylindrical bag over the barrel shaped bag that should be taken into consideration in any evaluation of the relative merits of the two are:

1) More complete bag extension

   a. The barrel bag hoops may tend to bind together in the collapsed position (stowage), whereas the cylindrical bag's hoops are of the same diameter and rest on each other when collapsed.

b. When in the extended position the weight of the barrel bag tends to collapse the curved walls of the bag inward resulting in an incomplete volume extension.

2) Simpler construction and fabrication

   a. Less seaming of patterns

   b. Less gore patterns

3) More efficient

   a. The cylindrical bag has been shown to be superior in static drops as well as actual parachute drops.

4) More economical to produce because of its simpler construction

5) Constant area of contact throughout the stroke resulting in a more constant work output (higher work output per psi at beginning of stroke).

Two other types of airbag configurations, a conical, and a skirt type bag, were considered. The first was a conic frustrum bag. A bag of this type will naturally, under loading, compress from the end with the smaller diameter. Thus, we have at the beginning of the stroke a small area of contact and low pressure. These increase slowly and the bag is well through the stroke before sufficient area and pressure is available for the bag to do any appreciable work. The bag also has one disadvantage in common with the barrel bag; that is, the hoops may tend to bind in the collapsed position preventing proper extension. For these reasons, the conical bag was considered unworthy of further investigation.

The skirt type bag was a long width of fabric stretched around the entire perimeter of the platform and hanging down freely. At ground contact the air would be trapped in the rectangular space between the ground and platform and restricted around the sides by the fabric. A model of the platform and skirt, however, was built and tested, and proved to be unsuccessful due to the large rate of air escape from under the skirt. A design of this type with an enclosed bottom was considered but found to be unpractical from the standpoint of weight and stowage space due to the large amount of material required and the gauge of the material required to withstand the high stress resulting from this type of design. The fact that this is, in effect, a single bag decreases the stability furnished to the platform. This design was therefore, discarded.

Airbag Dimensions

Airbag efficiency is influenced by the height/diameter ratio of the bag. The airbag stability will be decreased as this ratio increases but no maximum limit has been set for this value. The ratio should be kept as low as it is possible to comply with other requirements. The present ratio ($45/35 = 1.285$) appears to be within the allowable limit.

The pressure required in the bag for an efficient work output is determined by the bag diameter or the area of contact between the bag and platform. The present bag has a diameter of 35" and an area of 962 sq in. An increase in this area would result in a higher work output by the bag. The upper limit of the area, however, as set by the available space under the platform, has been reached.

Since the diameter, in turn, limits the stroke, as shown above, we feel that these dimensions are nearly optimum.

Bag Partitions

No information is available from actual tests on the effect of partitions with air metering devices within this type of airbag.

The result of such a partition would be a decrease in the rate of air escape from the bag after a point of the stroke determined by the position of the partition in the bag. This would cause higher pressures to build up in the latter part of the stroke.

It has been shown that higher pressures are more desirable during the initial part of the stroke to increase airbag efficiency and it can be seen that due to the direct relationship between pressure and G load, that an increase in pressure during the latter part of the stroke may not be tolerable due to the resulting G load increase.

Other disadvantages of an internal partition would be an increased weight and initial airbag cost. Servicing difficulties of an internal partition and orifice are obvious.

If the internal orifice were to become plugged by the compressing airbag, the result would be a ruptured bag or platform bounce. This plugging would be difficult to control during the angular descent of a parachute drop.

It is therefore our belief that no advantage could be gained by future investigation of this function that would offset the disadvantages shown here.

Prepressurization

Prepressurization is an attempt to obtain an approximately constant pressure throughout the stroke (see curve "A" of Figure 20) thus obtaining a steady work output by the bag throughout the complete stroke. This would theoretically result in a straight "G" curve which would be the lowest possible "G" peak" value for a given velocity and weight, thereby giving the bag 100% efficiency.

Obtaining a straight pressure curve would be unpractical of course, and unnecessary to comply with present decelerator requirements; however, we feel it is possible and desirous to approach this curve by prepressurization.

The present airbag is well through the stroke before sufficient pressure is built up for an effective work output by the bag. Part of the stroke is used to expand the sides of the airbag out to the maximum diameter then about 10" of stroke is often used to build up 2 psig pressure. Prepressurization would result in a more complete bag extention and an immediate work output by the bag.

Ample storage space is available under the platform among the intercostals and the increased weight would be a small percentage of the total weight of the load. The increased cost would have to be considered along with the triggering devices after the anti-toppling doors are swung open. Since the present airbags are made light as possible and are not completely impervious to air leakage, the timing of the inflation of the bags should be as close to ground contact of the load as possible.

Discussion

The original design was based on the use of a material which maintained its flexibility at low temperatures, and on an orifice which had a varying diameter dependent on bag pressure. Bags supplied have a minimum rubber coating and an orifice which is relatively stiff. The stiffness of this orifice is such as to give a bung release at approximately 6 psig bag pressure.

From the results of drop tests run on single bag platforms, it was noted that the orifice expanded and contracted during the deceleration period as anticipated, but the bung release was at too early a time to satisfactorily retard the higher energy input loads.

A revised orifice which was made considerably stiffer resulted in a higher bung release pressure and more energy absorbtion. For 1400# loads at 24 ft/s this orifice appeared to be nominal. However, for lower input energies there was slight bouncing, and for higher energies, ground impacts.

The bags, therefore, are for a nominal range of operation and improvement of the spread in the energy-input range appears feasible by variation in relief and metering design as well as by use of bag pressurisation, should that be desired.

Indications are that further work should be directed toward investigating the orifice and release pressure of the bung. An increase in required orifice area and/or bung size with the presently proposed platform cannot be made by keeping a circular configuration. An elliptical shape would allow for an area increase without conflicting with the intercostal platform stiffeners.

Use of a second ring which would be larger than the relief orifice and would act only to hold the bung until the proper pressure point appears to be desirable. With this system it would be possible to attain a high pressure relief point without sacrificing flexibility of the variable orifice.

In line with increasing the efficiency of the bags we have investigated, separately from this contract, a potential source for rapidly inflating the bags by use of explosives. The Pittman-Dunn Laboratory at Frankford Arsenal in Philadelphia was contacted and considers the problem presented to them as being fairly routine. Mr. LeVino of the Arsenal brought out that they would be willing to make a make-shift demonstration of the principles involved upon our supplying a bag.

Since it is our understanding that detailed work on this inflation system is beyond the scope of this contract, we are not prepared to enter into work with the Arsenal. However, if we supply requirements to the Arsenal, they are willing to furnish a proposal for time and money. This point is brought up in anticipation that WADC may want to consider rapid inflation with the prospect of increasing the efficiency of airbag deceleration and raising the energy absorbtion capabilities of airbags.

The final bag design must fulfill requirements of pressure, repeated use, proper extension under low temperature conditions and packagability.

Pressure - From drop test reports and the estimated range of bag loadings it appears that pressures up to 20 psig may be encountered. This pressure build-up is high in relation to the otherwise light weight and flexible construction that is required for the bags. It would require reinforcing the bags by use of circumferential hoops which would take some of the strain from the fabric and seams. This has already been done in previous bags.

Repeated Use: The bags are required to withstand repeated use. This is not a specific requirement; however, it is assumed that a minimum number of drops will eventually be specified.

The vulnerability of the bags cannot be definitely established; however, it is highly probable that besides the normal flexing and peak pressure conditions that will exist during drops, the bags will be subjected to abrasion and cutting actions of the platform and terrain. The main method of increasing bag life from an abrasion standpoint is the addition of protective coating. This, however, will result in a stiffer bag which may not perform satisfactorily in extending itself, prior to ground contact. Since the requirement for full extension is greater than abrasion resistance (in that a non-extended bag would be of little use in a drop, whereas an extended bag which had to be replaced after a limited number of drops would at least have served to good use for the limited time). We would say that additional protective coating was a secondary requirement to be satisfied only after bag extension characteristics were met.

Bag Extension: The prime concern is that the bag will fully extend under low temperature conditions.

To determine the bag "extensibility" and obtain correlation with a test procedure, two types of tests were made. A bag was made up to the proposed dimensions and construction, then packaged into its collapsed state. This package was then subjected to low temperatures in a cold room, conditioned, and then released. The amount of extension was noted.

The Control Test was the Gehman Cold Torsion Modulus Test:

Figures 29 and 30 show tests on plain compounds and nylon reinforced compounds.

An airbag made up of material (1), Figure 30, extended 18" and 14" in two tests. The Gehman test on this fabric for -40°C showed a twist of approximately 164° vs. an original of 166° at room temperature.

Bag made up of material (2), Figure 30, did not extend appreciably when released. This has Goodyear Compound 52904 in its main makeup.

From the cold Torsion Test on compound alone, it is apparent that Goodyear Compound 28601 has the greatest potential for use at low temperatures while still maintaining flexibility.

Goodyear Compounds 70940 and 52904 are approximately the same but somewhat poorer in flexibility than the Goodyear Compound 28601. We have processed nylon cloth with the Goodyear Compound 28601 for manufacturing into a bag and expect that this will be the ideal fabric for flexibility.

Beside the flexibility of the compound, the stiffness is also dependent on over-all gauge of the final material. This gauge is being kept to a minimum for the tests.

To obtain improved extensibility of decelerator bags, additional materials were investigated. Initially this investigation was checked by running Gehman Cold Torsion Modulus Tests, to discover relative improvement over past materials.

Figure 31 shows the results of four materials investigated and compares them with the initial materials.

Although there appears to be only slight improvement of the rubber compounds over the neoprenes (1) and (4) at -40°F, the difference is much more noticeable at lower temperatures.

Cold chamber tests of bags made from material numbers (1), (2), (8) and (9) resulted in the following table:

Material No.	% Extension @ -40°C				% Twist from Gehman at Temperature °C		
	Baseboard		Weight -#		-40	-50	-60
	0	4	4.7	7			
1	50	63		100	100	71	50.5
2		0			66	46	33
8	82		100		100	59	88
9			90		100	97	79

This table also shows results from the Gehman Cold Torsion Test. The percent twist figure was obtained by comparing the twist at the temperature noted with the original twist made at room temperature.

The difference between the cold box extension test and the Gehman Modulus test are such that no positive correlation can be made. However, it appears reliable to show trend direction.

A third influencing factor in the cold tests is the possible freezing of moisture on the bag. The tests made on the assembled bags did not take this freezing into account. In the packaging specifications it will have to be brought out that with sub-freezing conditions the bags will have to be completely dry so that the material when collapsed in the package will not freeze to itself after packaging. This may not be a practical consideration and investigation is to be continued on lubricating the bags with graphite.

Packagability: The bags must be able to be packaged into approximately a 3 to 4 inch depth. This is a minor problem with the barrel shaped bag in that any hoops used telescope inside of one another. The present barrel shape has given no trouble with packaging.

A cylindrical bag is the best shape from a design strength, and cost of manufacturing basis. Its main limitations are poor packagability if reinforced with metal hoops and poor stability if used as a single unit under a platform.

These two factors are not of great concern, however, in that if a cylindrical bag is otherwise allowable, the decreased stress condition would allow for less material in the hoops. The hoops would also become less essential in bringing the bag cross section out to a circle. With the barrel bag, hoops were necessary to pull the bag circumference out fully.

From the standpoint of stability, a cylindrical bag would be satisfactory if used in multiple units under the platform, so long as a normal ratio of stroke/diameter is maintained. Platform toppling due to uneven loading or horizontal movement will tend to be corrected by a cylindrical as well as a barrel bag.

Bag Components: The main bag component is the orifice. Its area and method of regulating bag pressure, as well as its expendability and simplicity of design, are important factors.

To insure a positive and predictable bag performance, the orifice must be consistent in its action. The most satisfactory system of relief is a metal orifice with a blow-out plate, the plate being fitted to the orifice with a steel gasket and shear pin. Results obtained on this type of relief show that consistent blow-out pressures can be attained. The orifice and plate is heavier than rubber components and is fairly difficult to install. From the standpoint of simplicity, this type of orifice is undesirable.

It has been noted in the study that the relief point where the orifice plate blows out is not too critical. If blow-out occurs at an approximate pressure of 6 psig, the bag will perform well. With this in mind, development work has been initiated to make an orifice and plug which will hold the pressurized air in the range of 6 psig.

The second desired design on the orifice is a variable diameter. For proper functioning the spring or extensible circumferential restriction must be developed for proper design. This is a combination of material as well as design development.

Attachment fittings to tie the bag to the platform will be of a snap-on type to permit ease of installation as well as release under stress as the platform moves horizontally with the ground at contact.

ORIFICE FLOW

Graph with x-axis labeled "PI — PSIG" ranging from 0 to 12, and y-axis labeled "FLOW WEIGHT — # / SEC / SQ. FT." ranging from 0 to 70. A curve labeled "600°" rises from the origin.

FIG. 1

VOLUME & AREA VS. STROKE
38 X 24 X 34 BARREL

FIG. 2

FIG. 3

$$P = C \left(\frac{W}{V}\right)^{1.4}$$

ABSOLUTE PRESS — PSI

$\frac{V}{W}$ — $\frac{Ft^3}{\#}$

C = 552.5
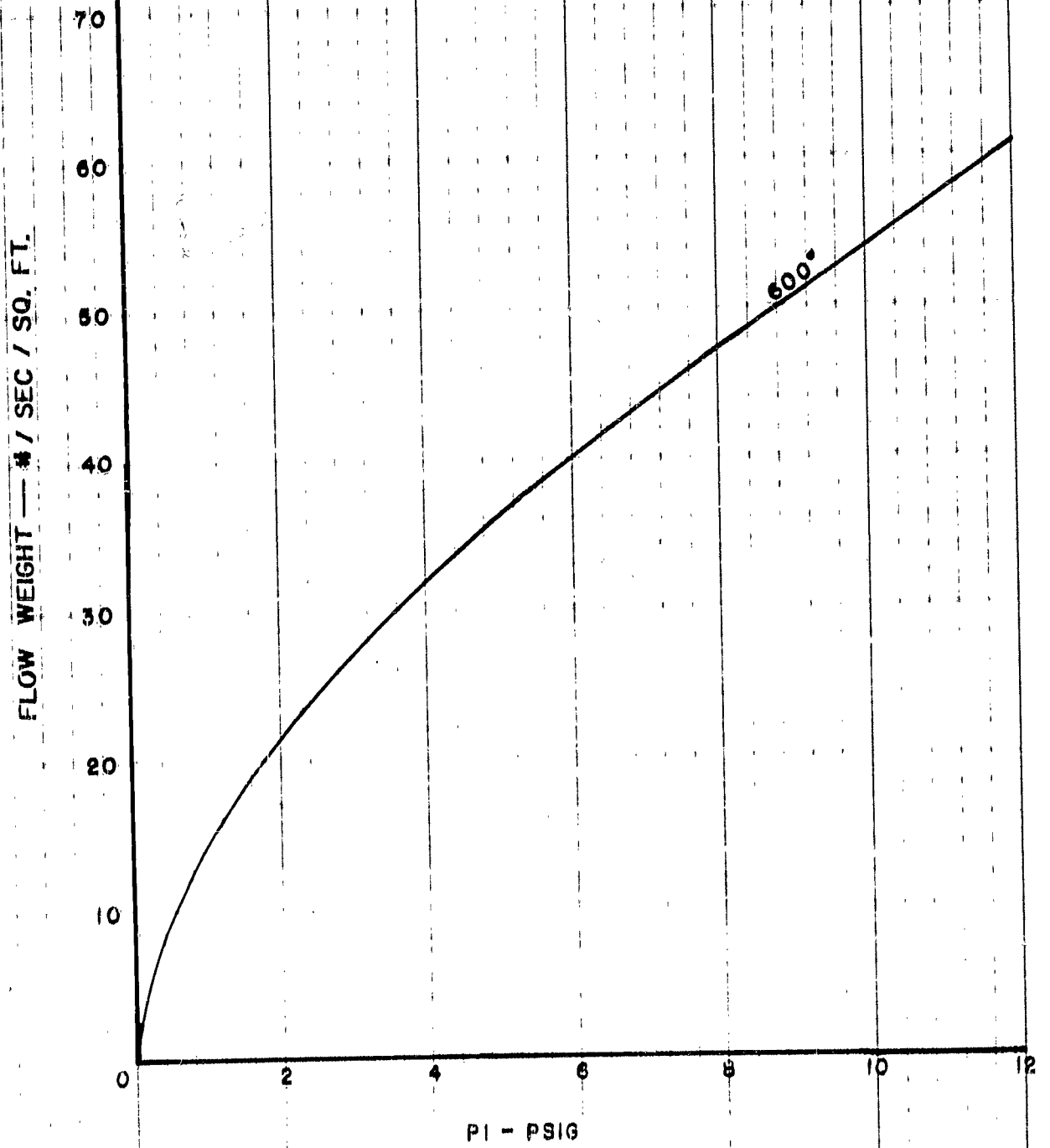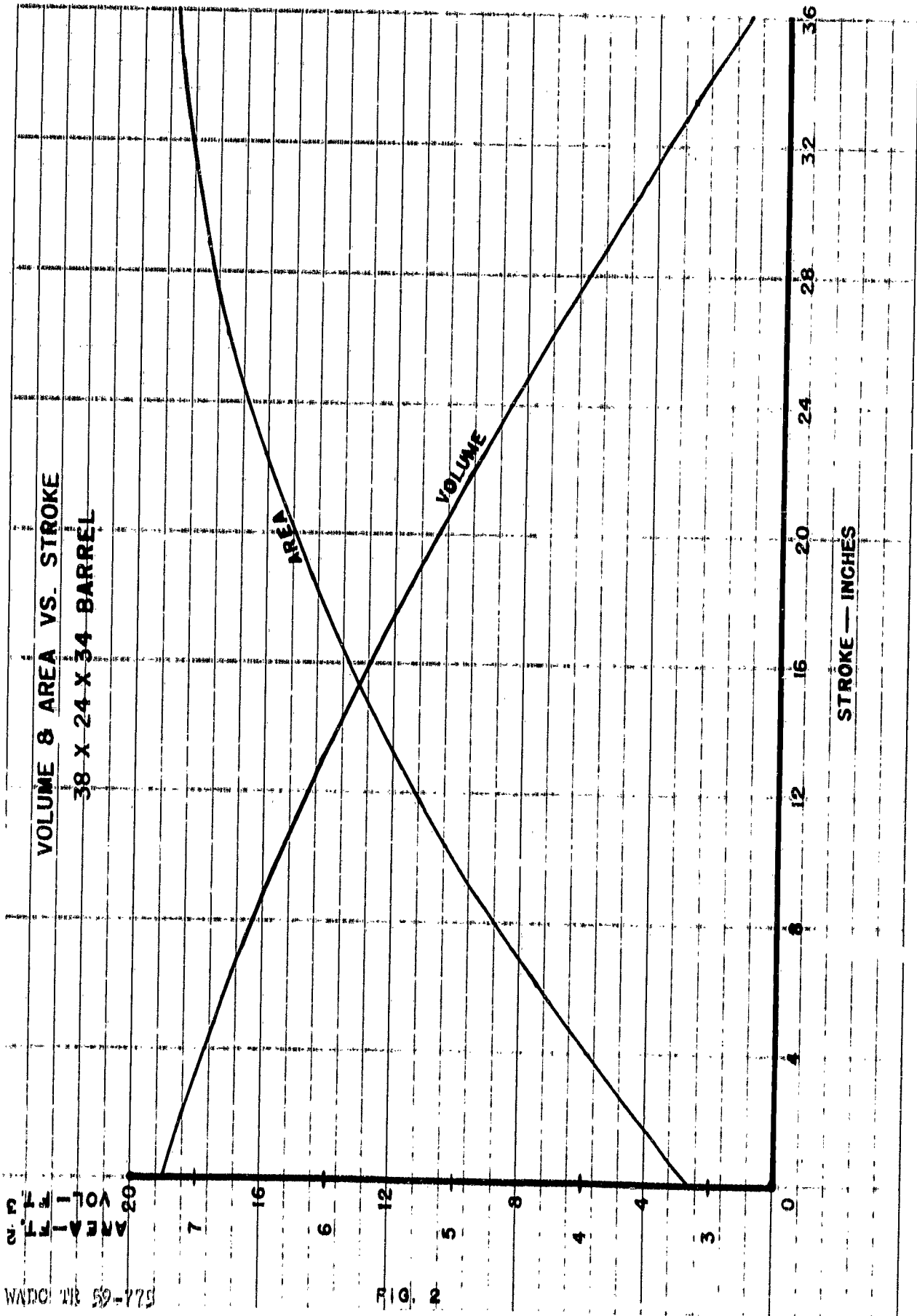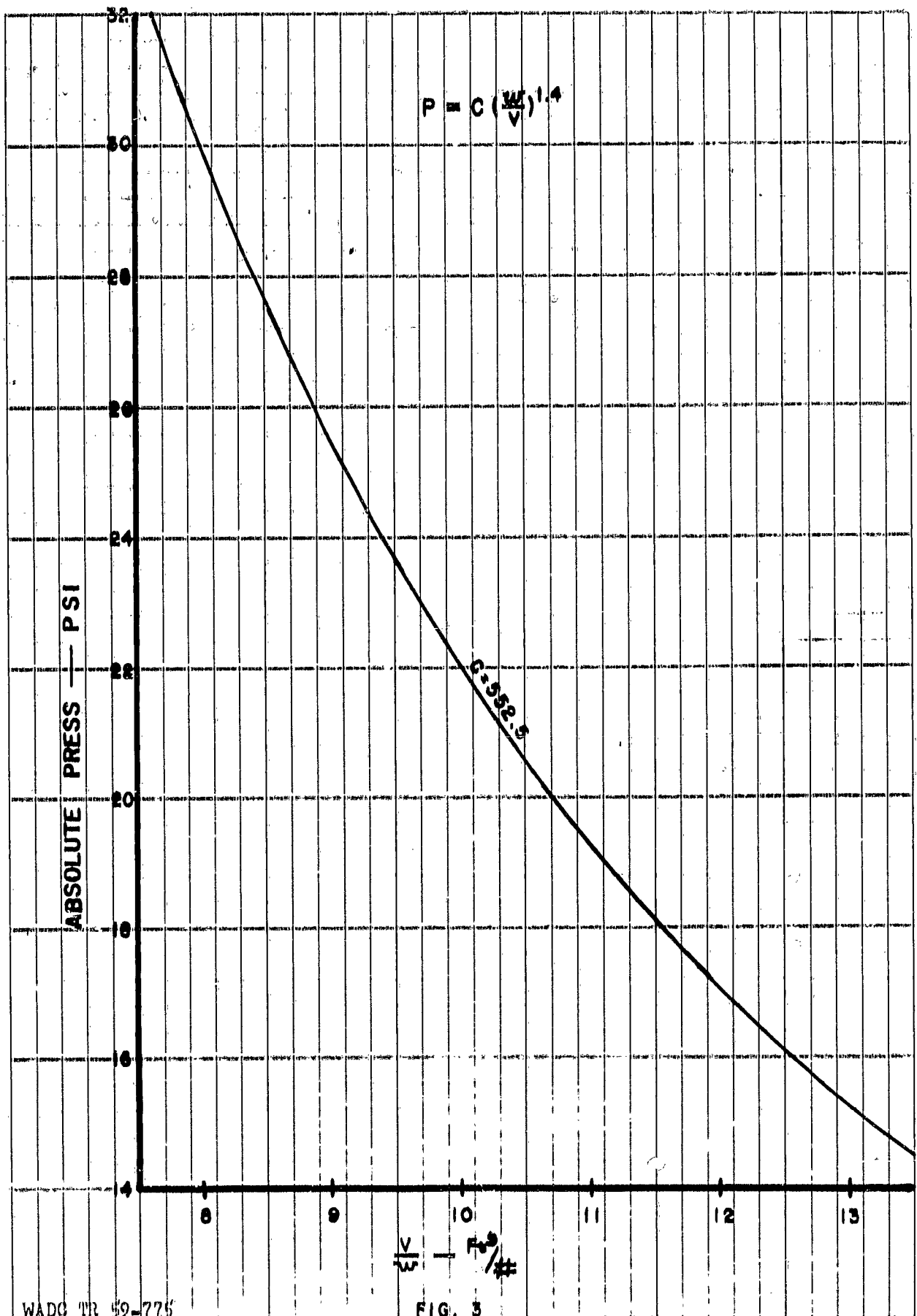
CORRELATION
THEORETICAL VS. TEST DROPS

MEAN AREA VS. ORIFICE DIAMETER
FOR OPTIMUM PERFORMANCE

P MAX & G MAX PARAMETERS

WCLE 53-147, FIG. 10
4" DIA. X .010" GA.
W = 800#

$P = \#/\text{IN}^2$ $V = \text{FT/SEC}$

V

P

G

STROKE — IN.

WCLE 53-147, FIG. 11
4" DIA. X .010" GA.
W = 800#

$P = \#/\text{IN}^2$ $V = \text{FT./SEC.}$

V

P

G
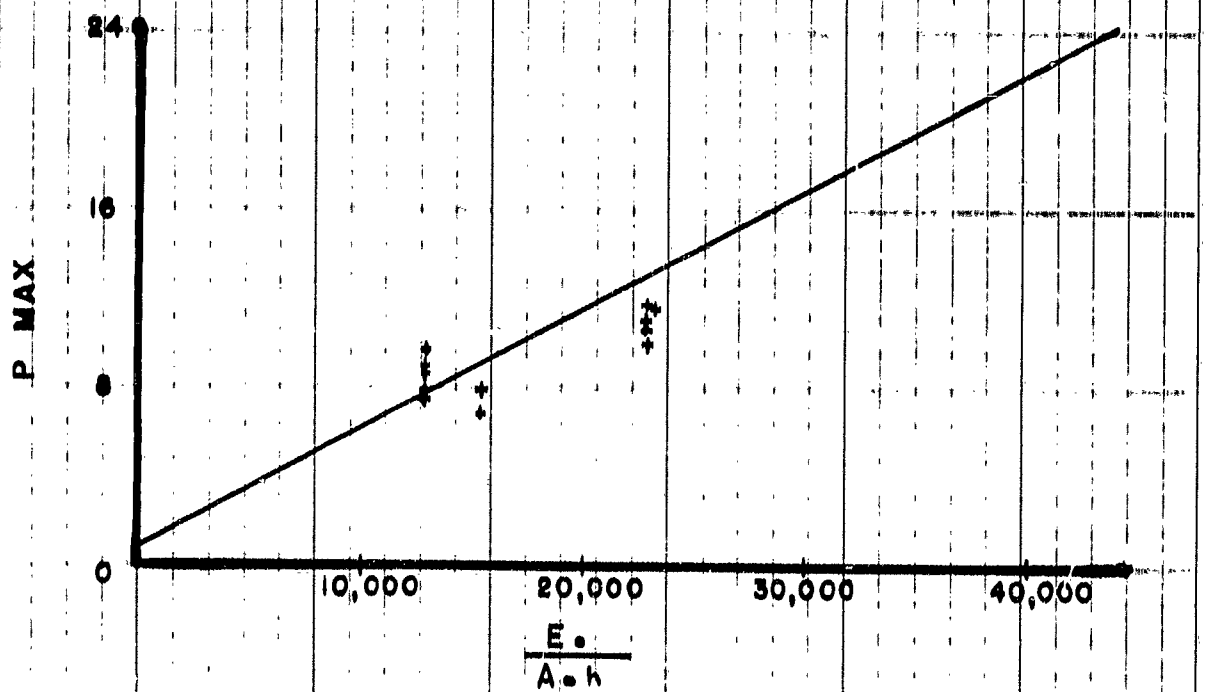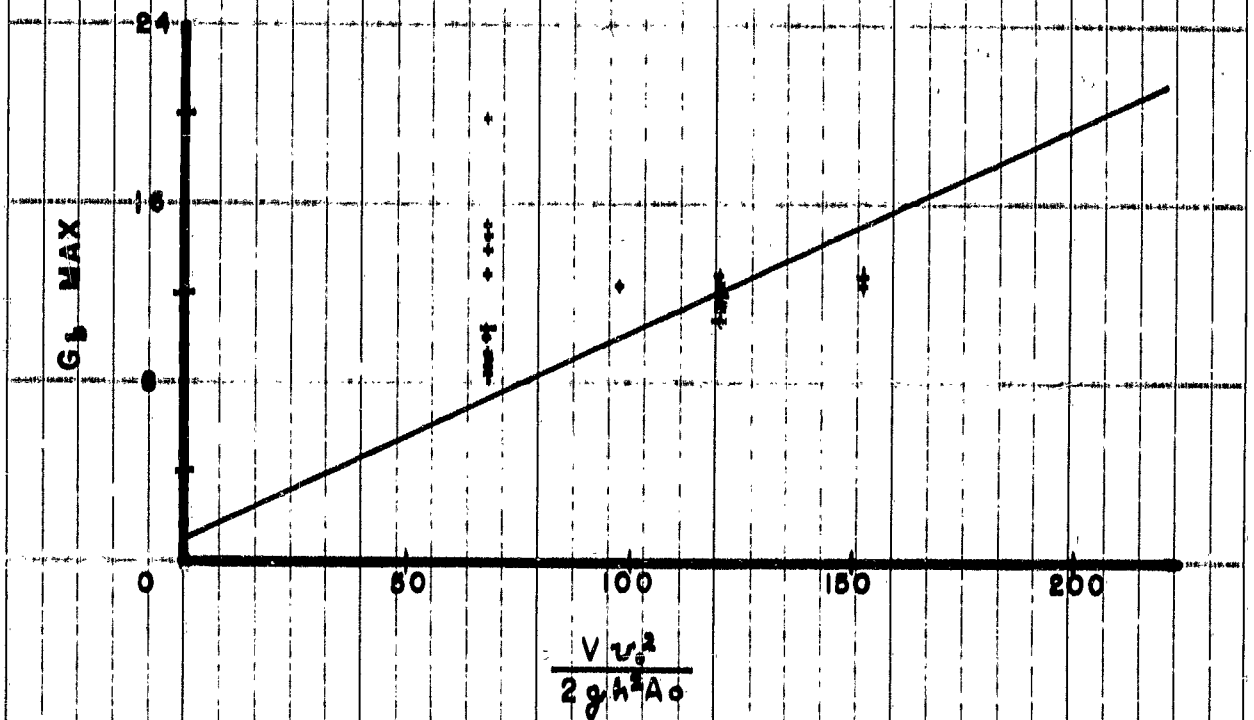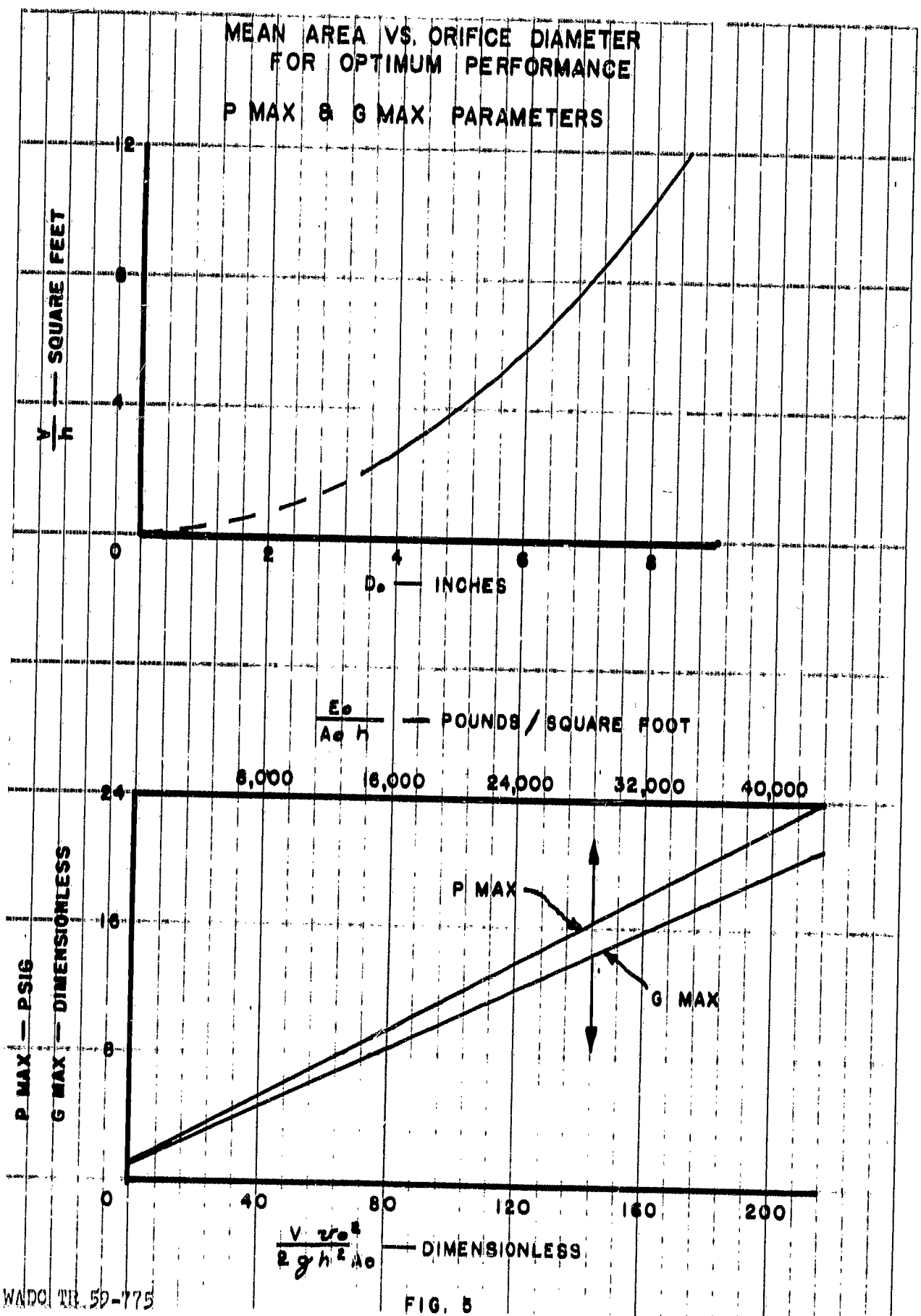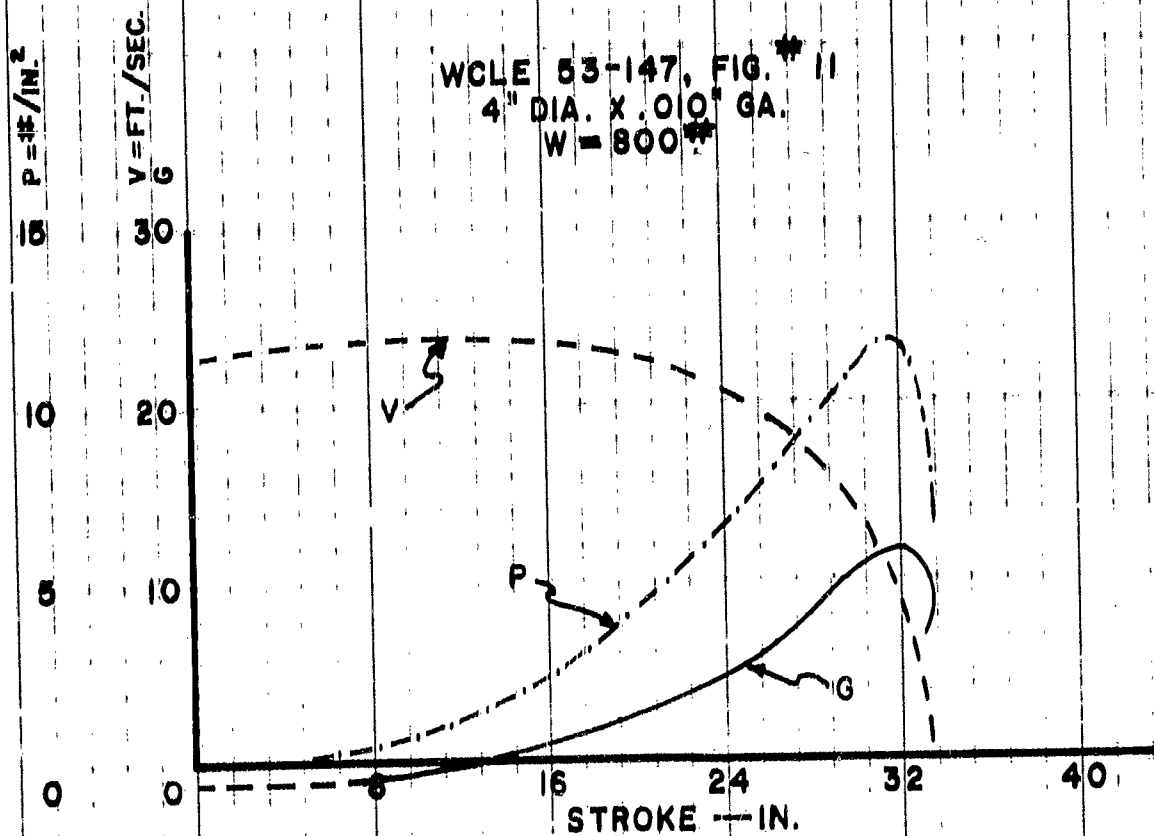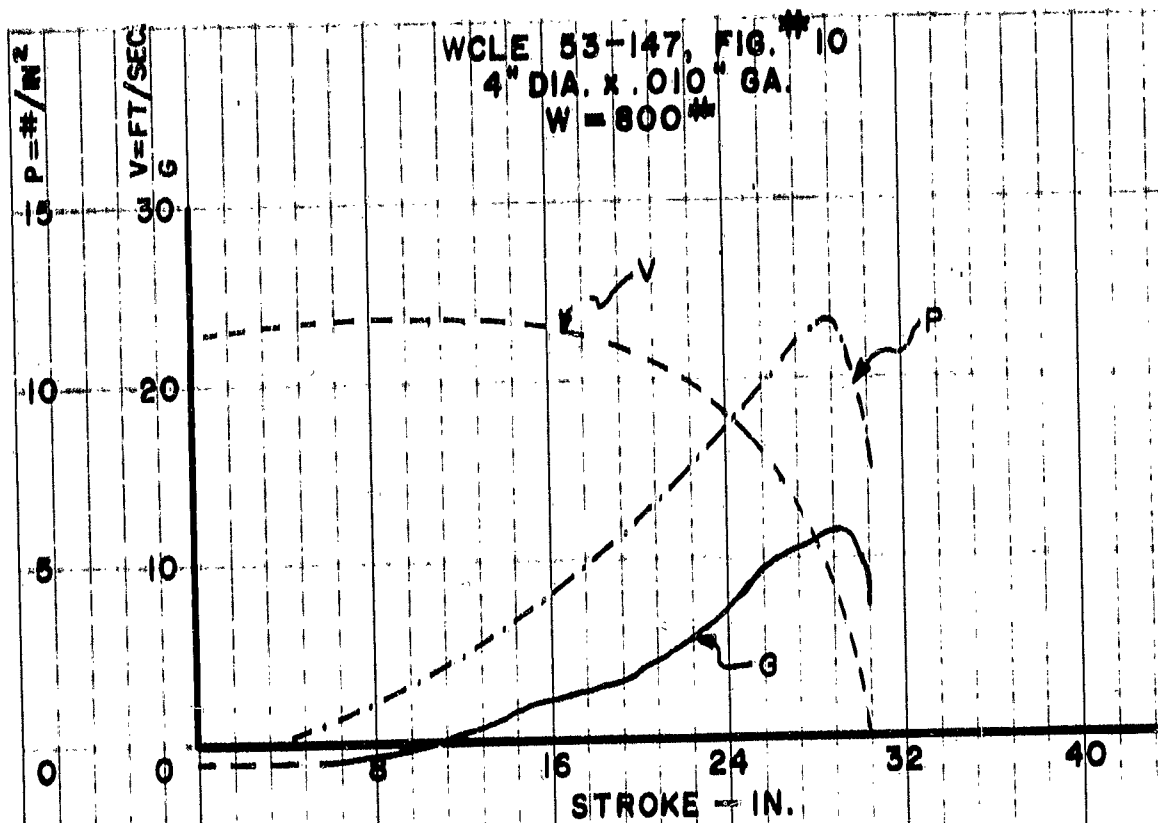
STROKE — IN.

NOTE: ABOVE CHARTS SUPERIMPOSED GIVE NET STROKE OF 28.5 IN.

WADC TR 59-775

FIG. 6

36

WCLE 53-147, FIG. 12
4 ½" DIA. X .010" GA.
W = 800 #
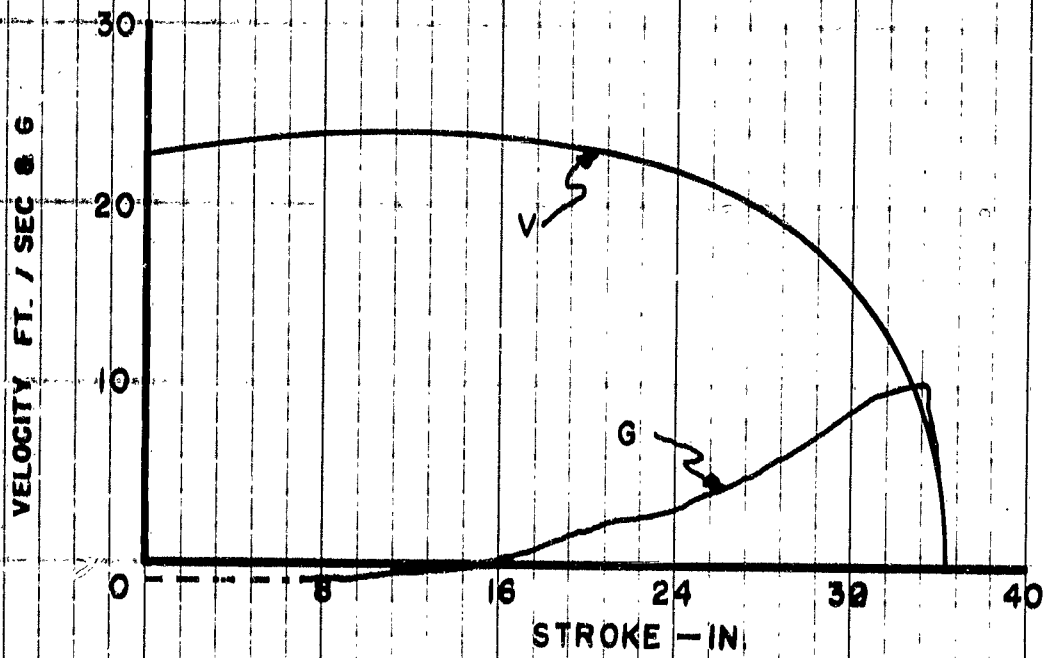
WCLE 53-147, FIG. 14
4 ½" DIA. X .010" GA.
W = 800 #
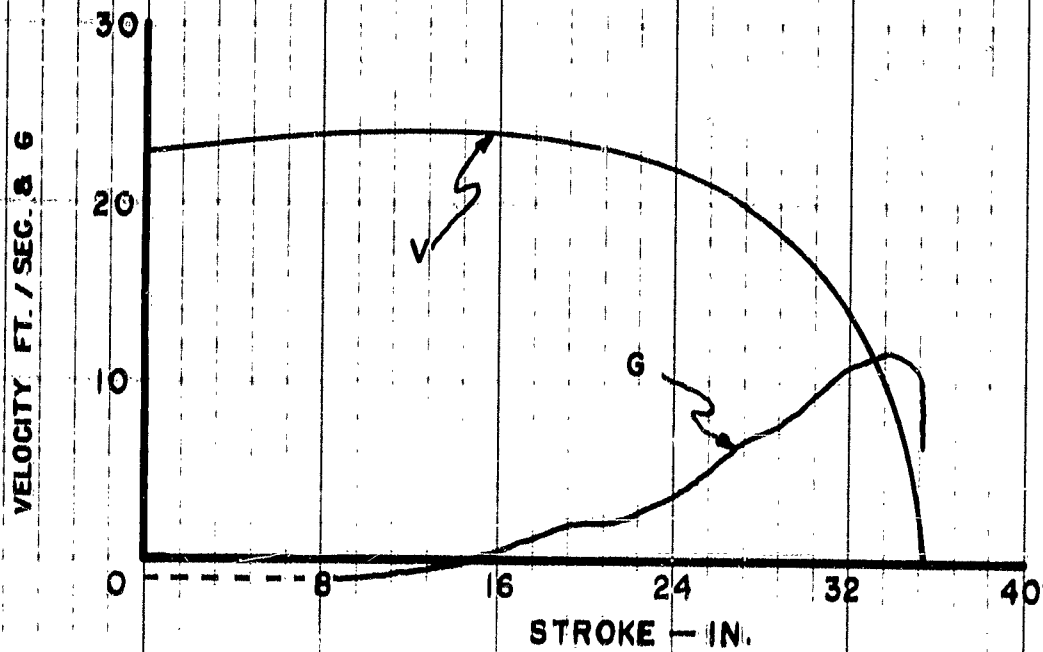
FIG. 7

WCLE 53-147, FIG.15
5" DIA. X .010" GA.
W = 800#
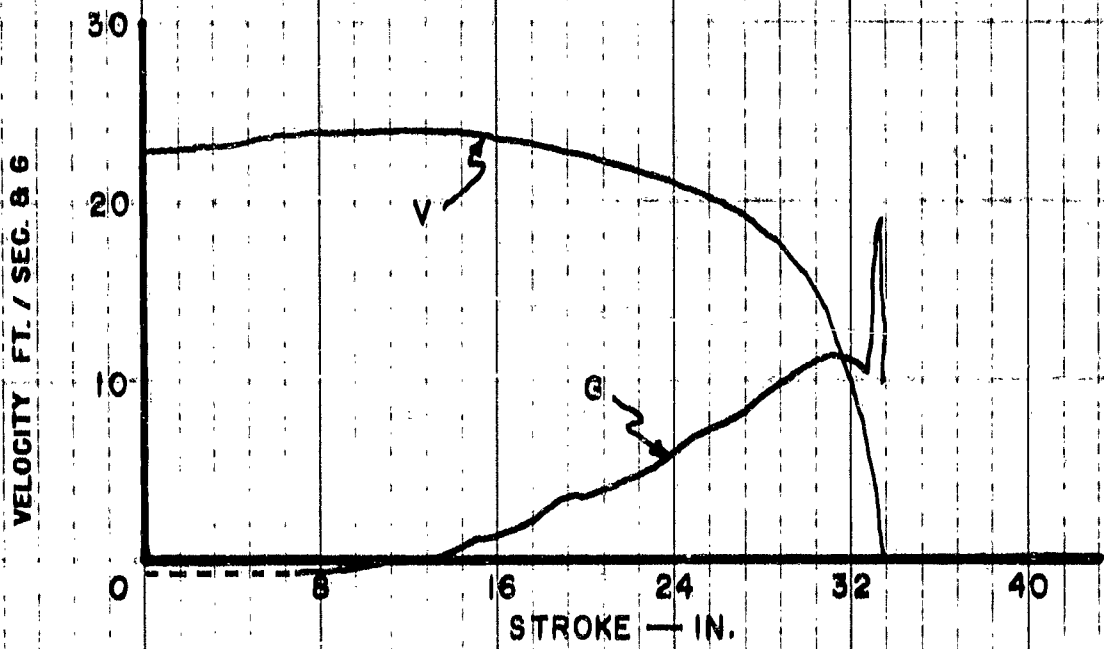
WCLE 53-147, FIG.13
4½" DIA. X .010" GA.
W = 1000#

FIG. 8
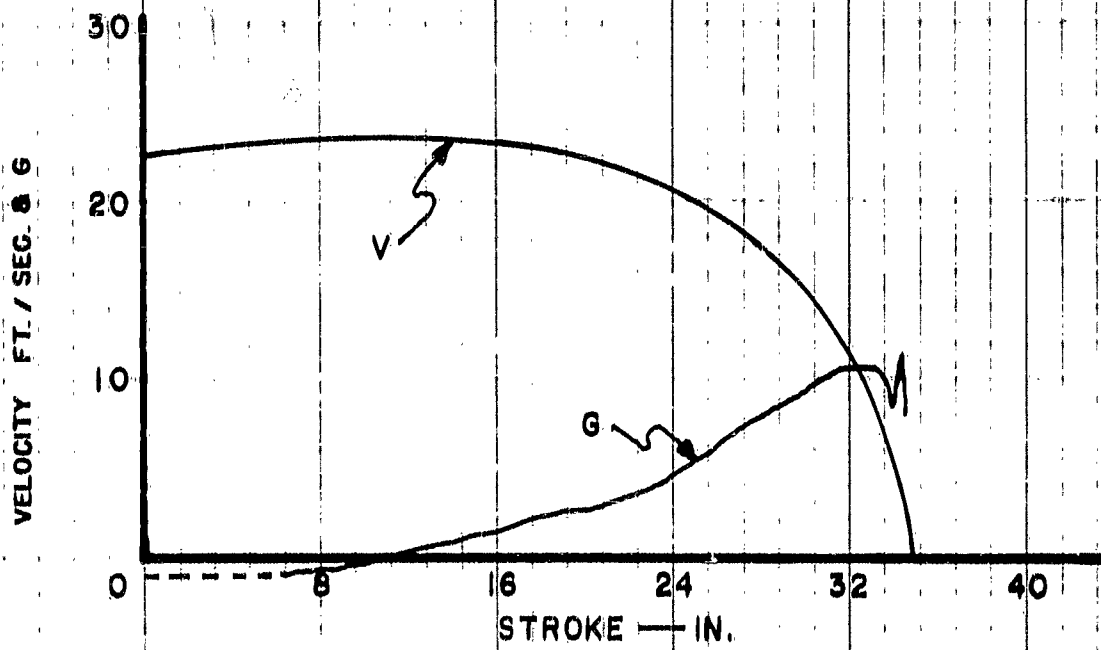
WCLE 53-147, FIG. 21
4 ½" DIA. x .040" GA.

WCLE 53-147, FIG. 18
4 ½" DIA. x .028" GA.

FIG. 9

WCLE 53-147, FIG. 20
4½" DIA. X .032" GA.
W = 1000 #

WCLE 53-147, FIG. 19
4½" DIA. X .020" GA.

FIG. 10
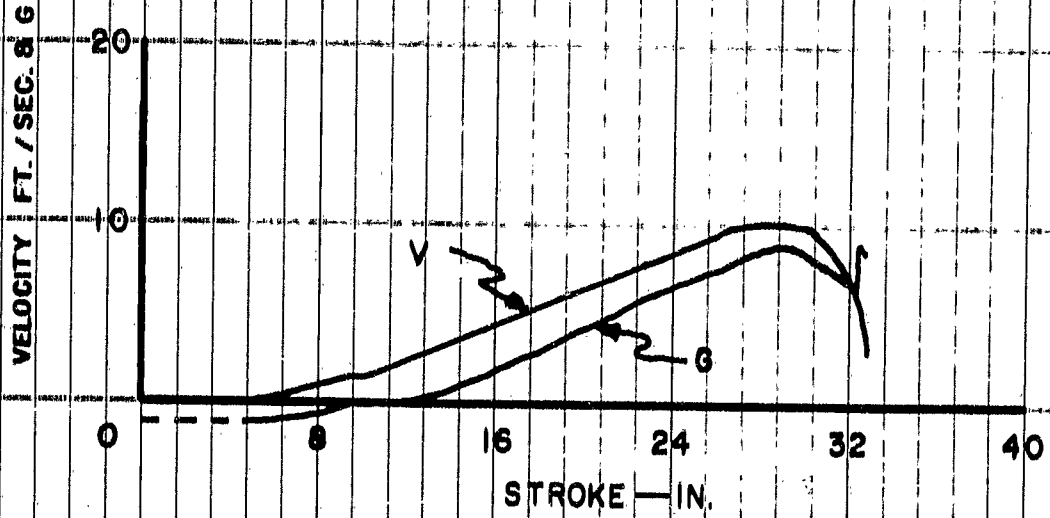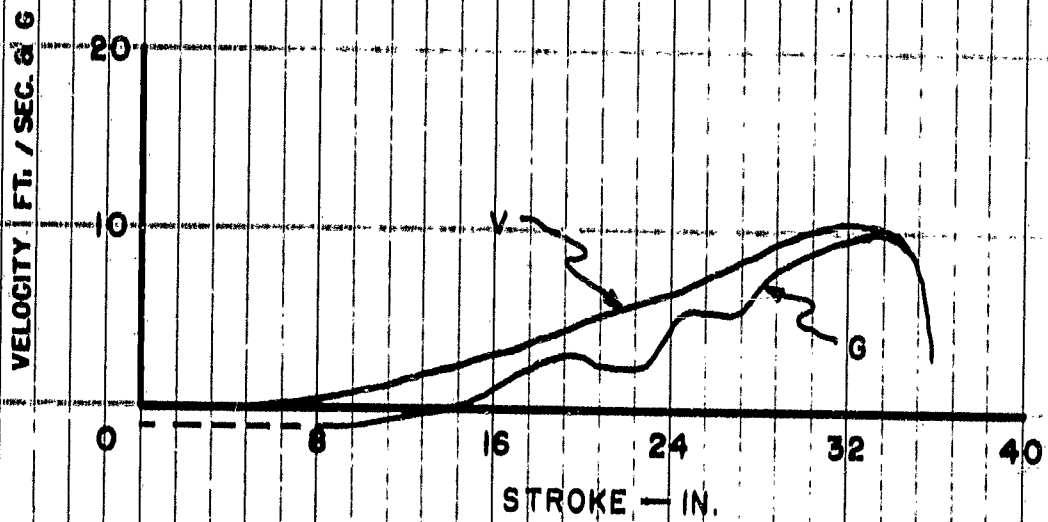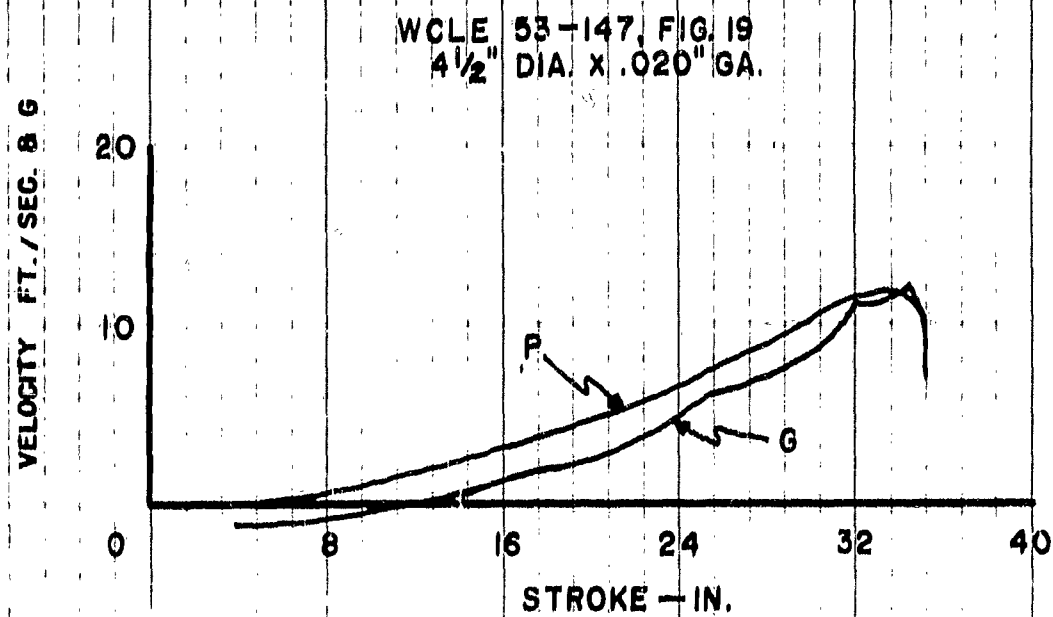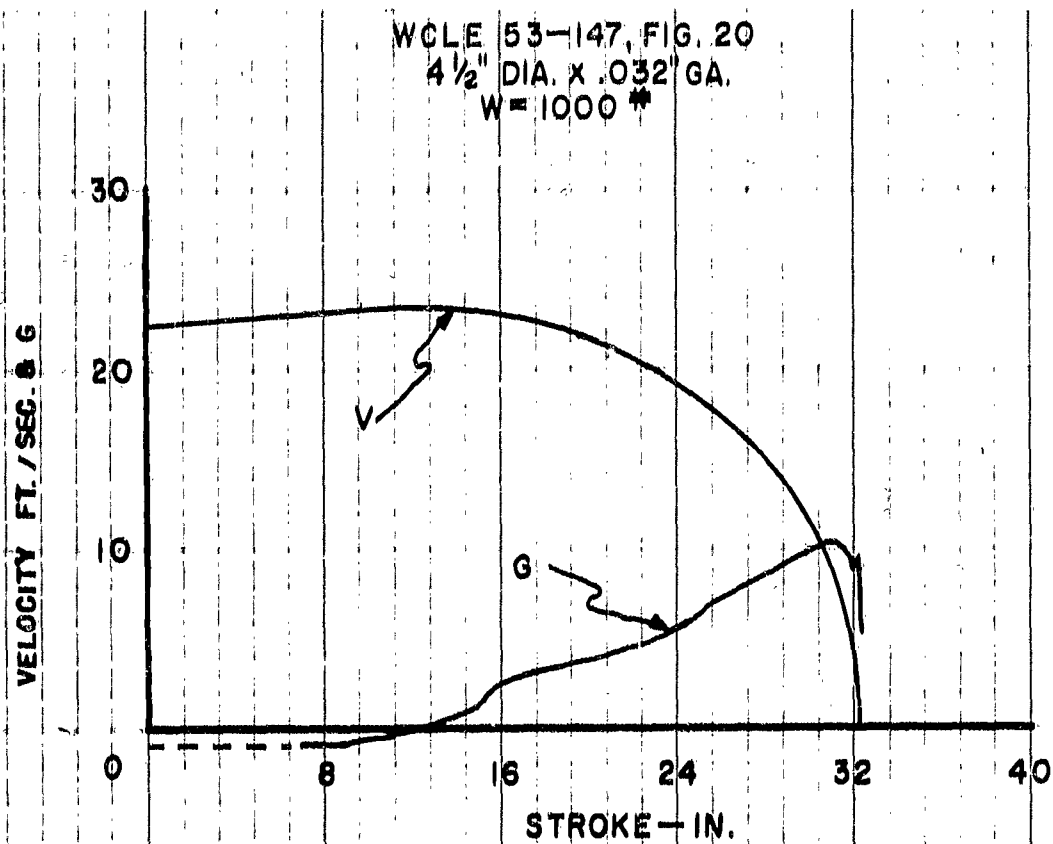
WCLE 54-11, FIG. 21
6" DIA. X .010" GA.
W = 1000 #
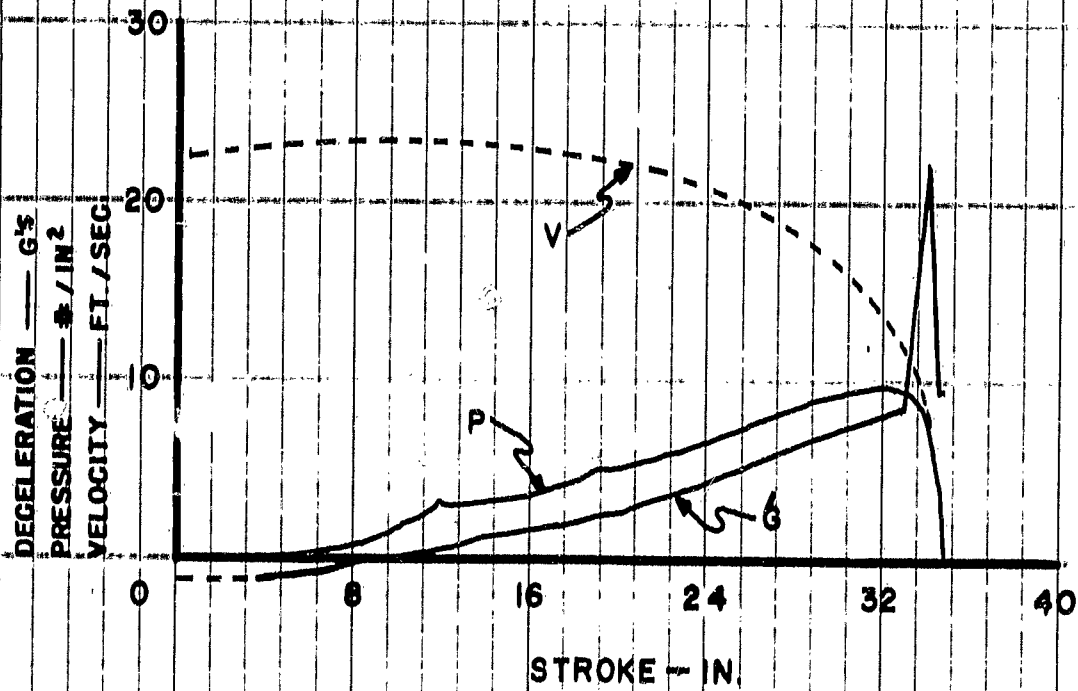
FIG. 11

WCLE 53-147 FIG. 16
6" DIA. X .010" GA.
W = 1000 #
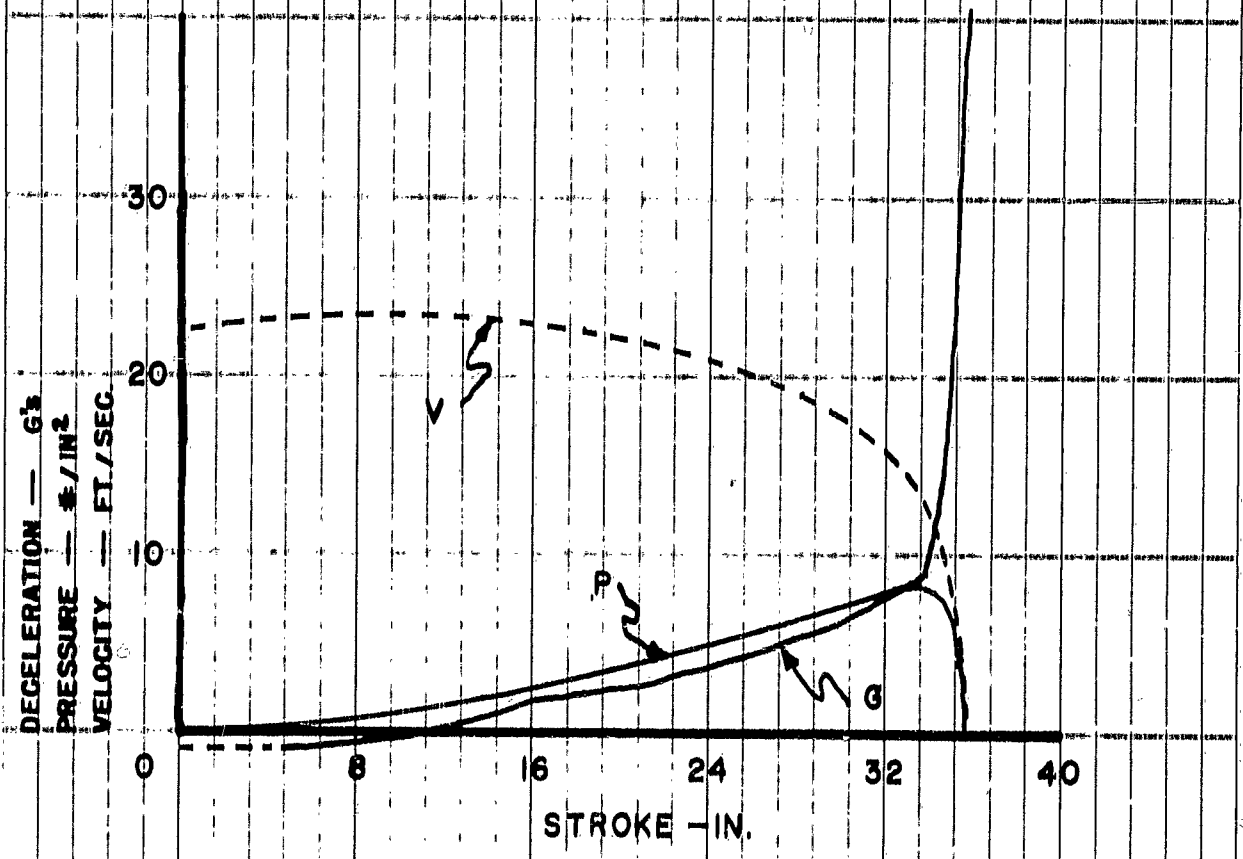
FIG. 12

WCLE 54-11, FIG. 24
6" DIA. X .020" GA.
W = 1000 #
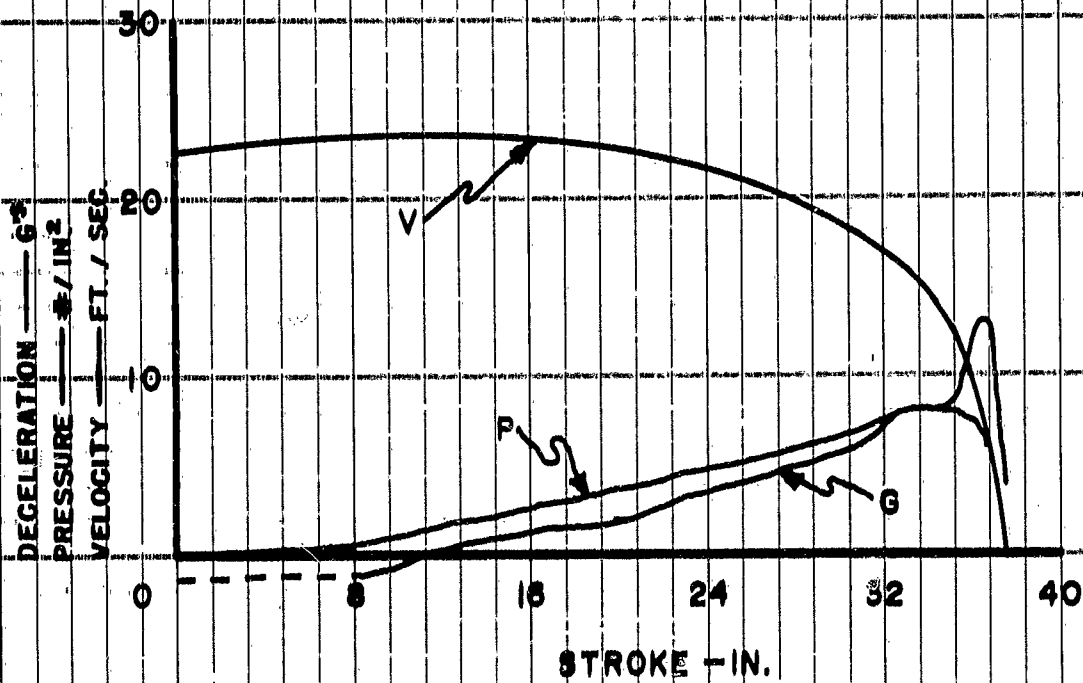
FIG. 13

WCLE 53-147, FIG. 23
6" DIA. X .020" GA.
W = 1000#

WCLE 53-147, FIG. 25
6" DIA. X .040" GA.
W = 1000#

FIG. 14
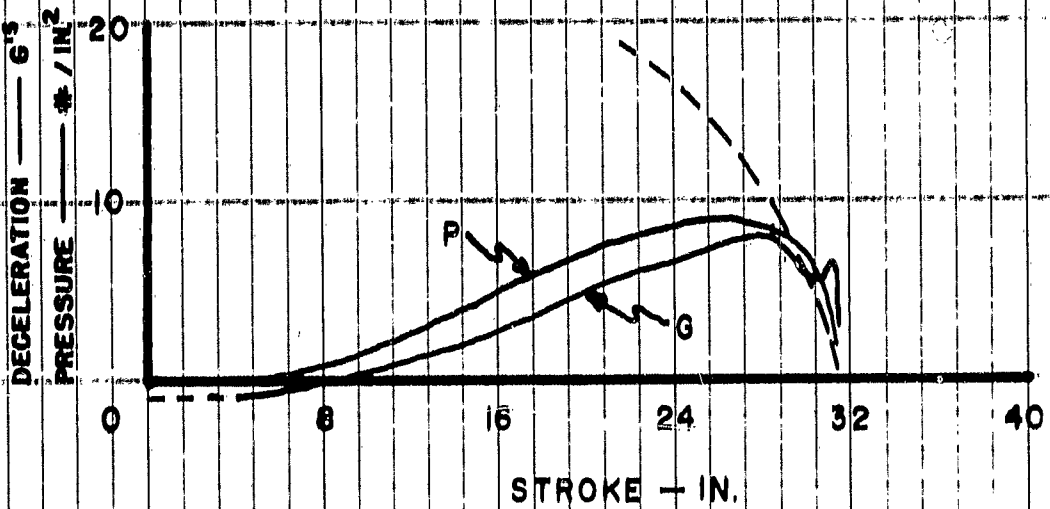
WCLE 53-147, FIG. 22
6" DIA. X .028" GA.
W=1000*

DECELERATION — G'S
PRESSURE — #/IN²

20

10

0

0   8   16   24   32   40

P

G

STROKE — IN.
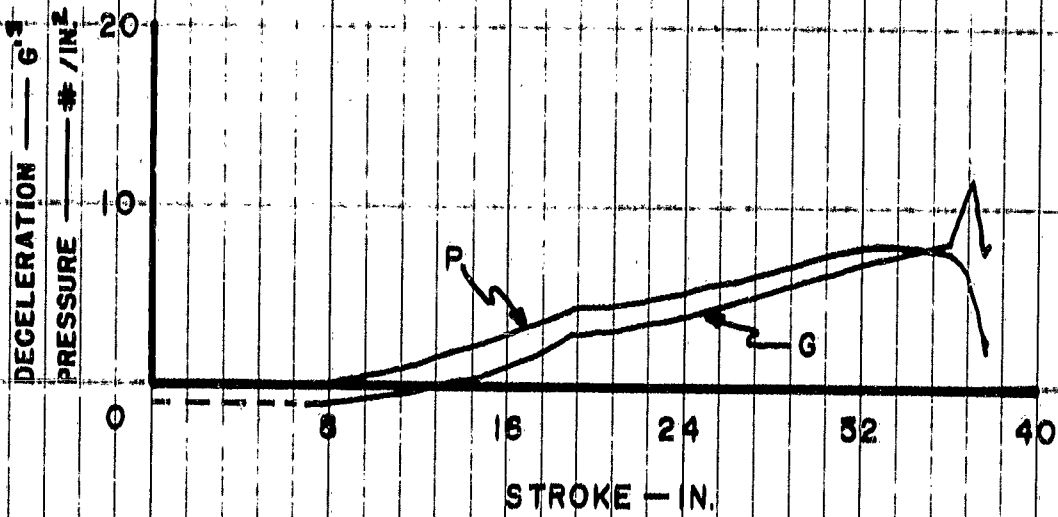
WCLE 54-11, FIG. 25
6" DIA. X .032" GA.
W=1000*

DECELERATION — G'S
VELOCITY — #/IN²

30

20

10

0

0   8   16   24   32   40

STROKE — IN.
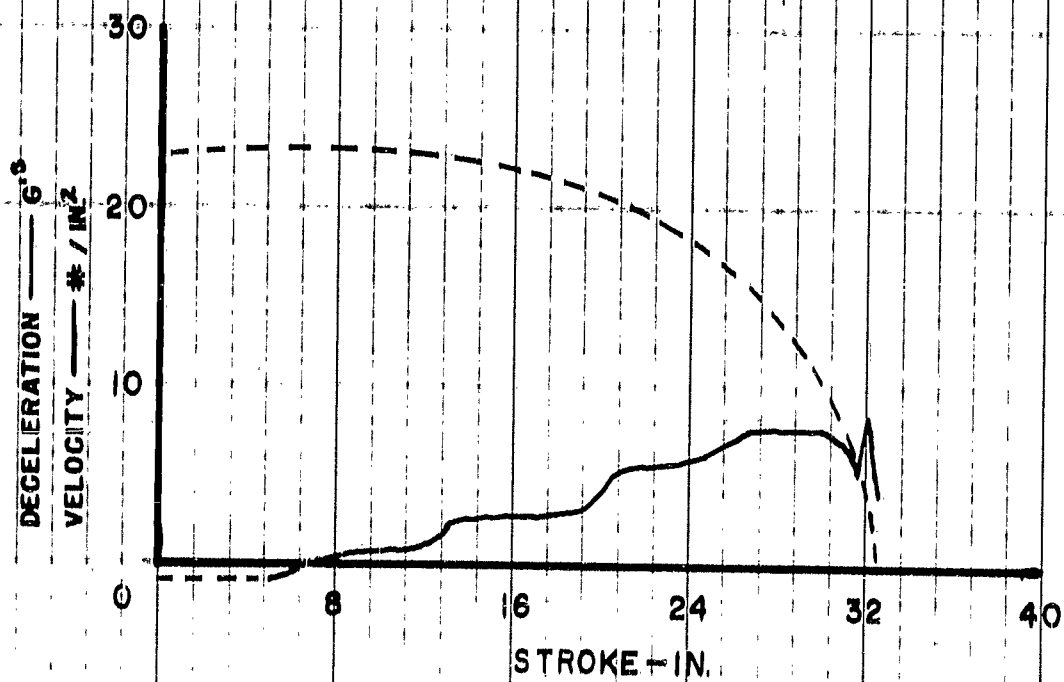
WCLE. 53-147, FIG.24
6" DIA. X .032" GA.
W=1000#
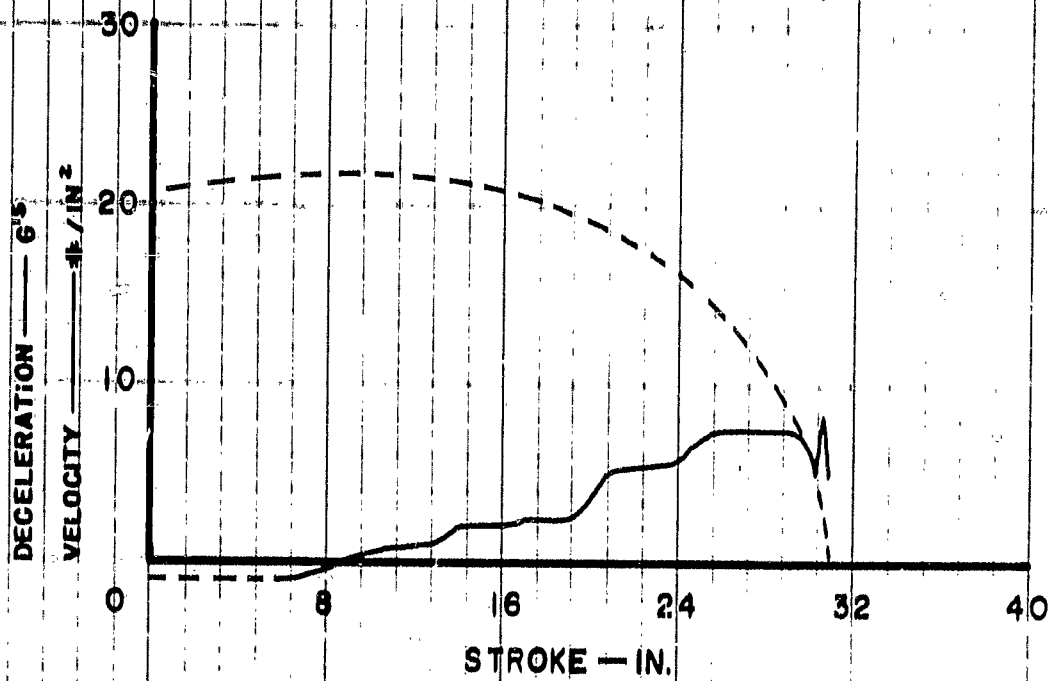
FIG. 16

WCLE. 53-147, FIG. 17
6" DIA. X .036" GA.
W=1000 #

CORRECTED TO GIVE IMPACT @ 34" STROKE

DECELERATION — G^S

VELOCITY — #/IN^2
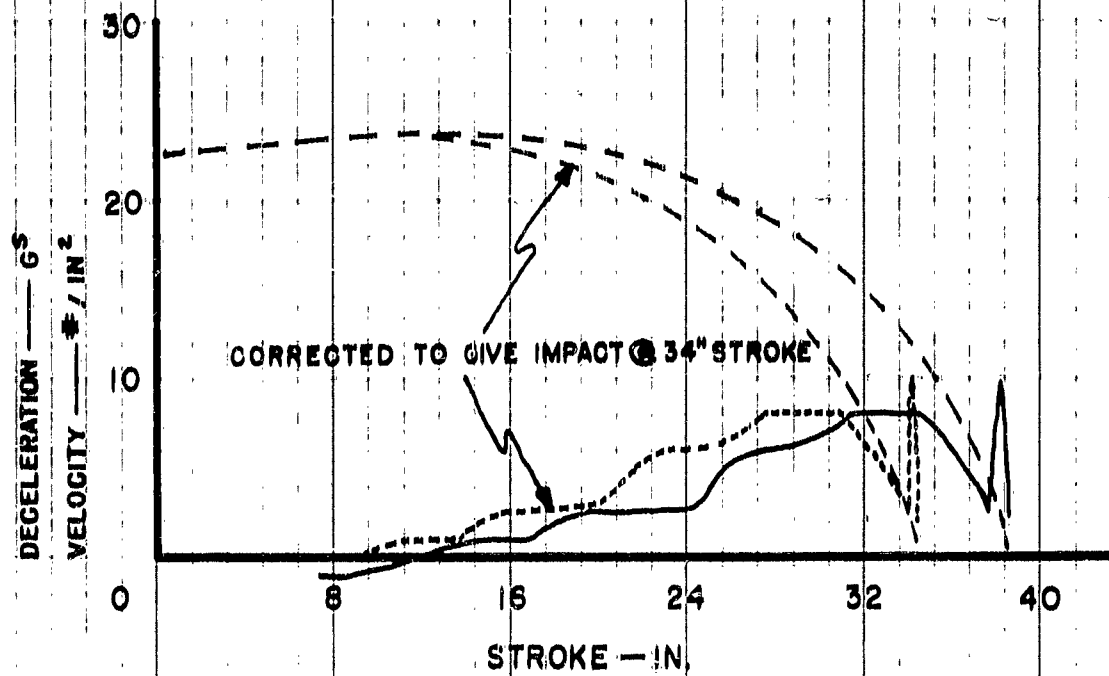
STROKE — IN.

WCLE. 54-11, FIG. 20
6" DIA. X .020" GA.
W = 1200#
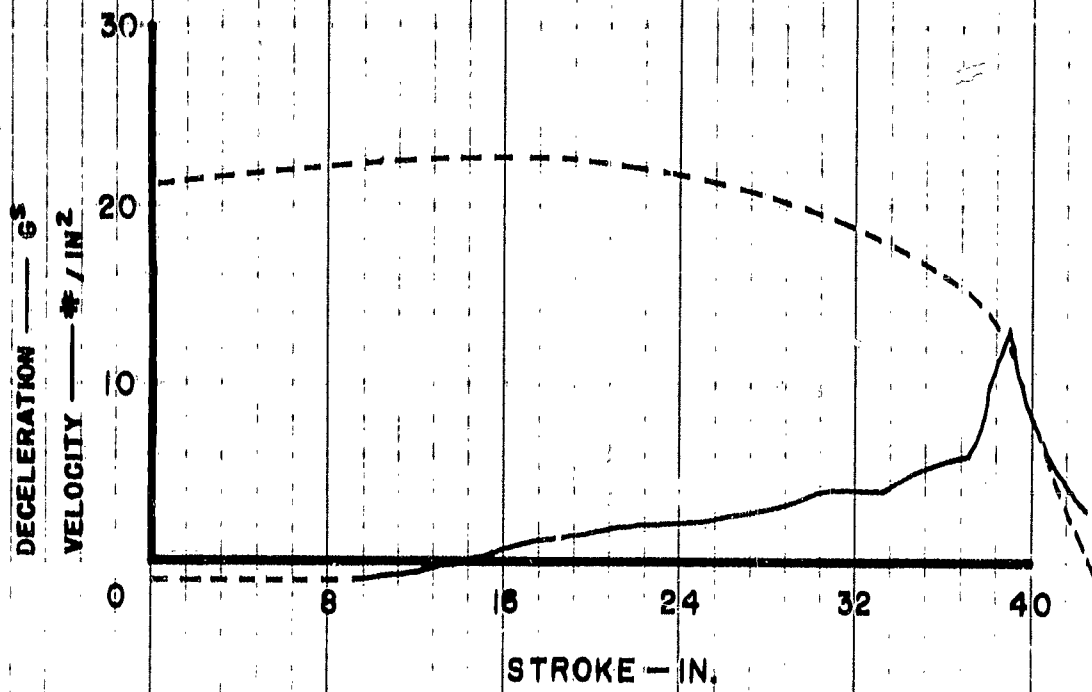
FIG. 18

CORRELATION
THEORETICAL vs. DROP TESTS

G_b MAX

$Vv^2/2gh^2Ao$

P MAX

Eo/Aoh
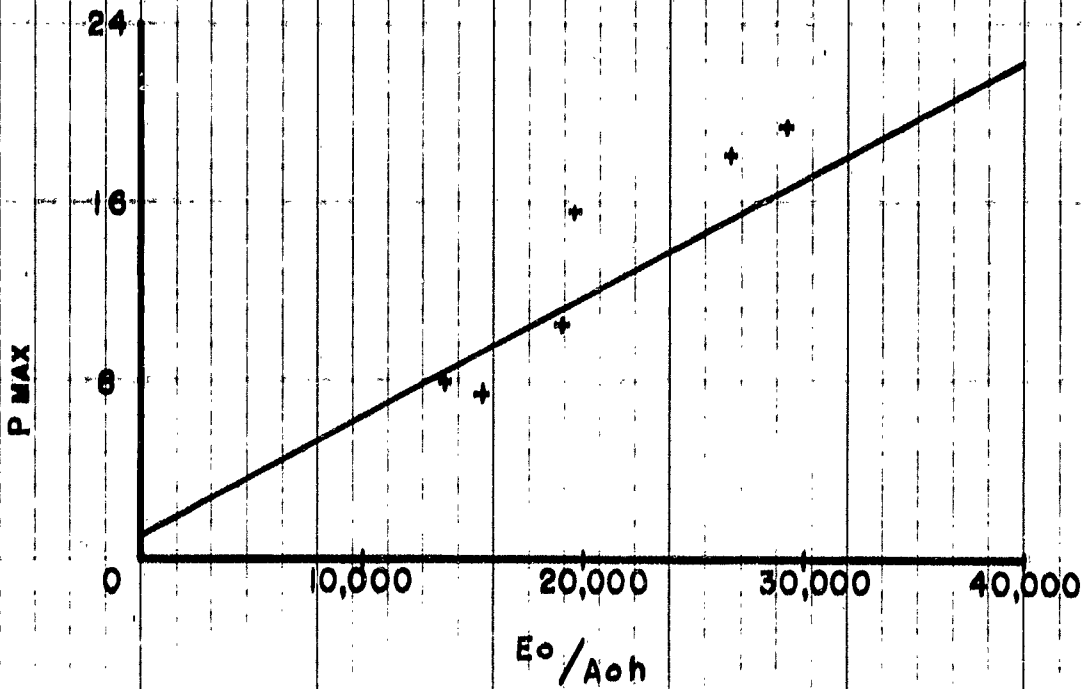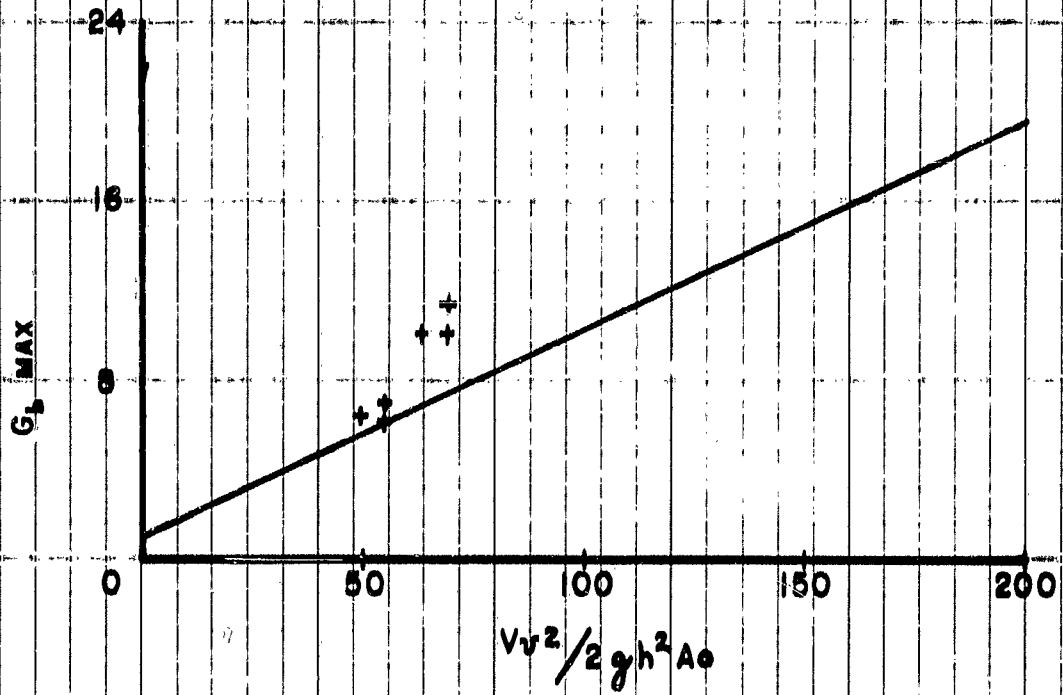
EFFECT OF BLOWOUT PRESSURE

"D" PLUG BLOW OUT

"C" PLUG BLOW OUT

SINGLE BAG TEST RIG FOR FREE FALL DROPS

HI-SPEED CAMERAS

X AXIS CH.#5 ACCELEROMETER

Z AXIS CH.#6 ACCELEROMETER

Y AXIS CH.#7 ACCELEROMETER

CH.#2 PRESSURE CELL

WEIGHTED PLATFORM

AIR BAG

FILM MARKER
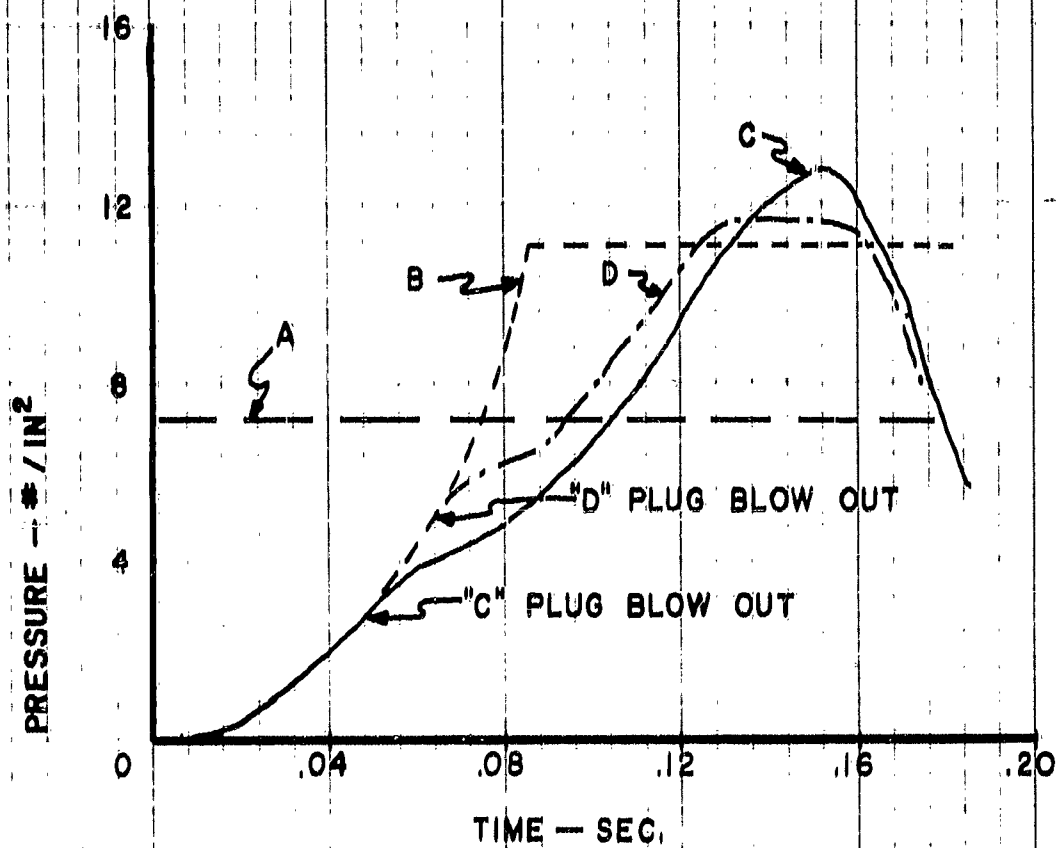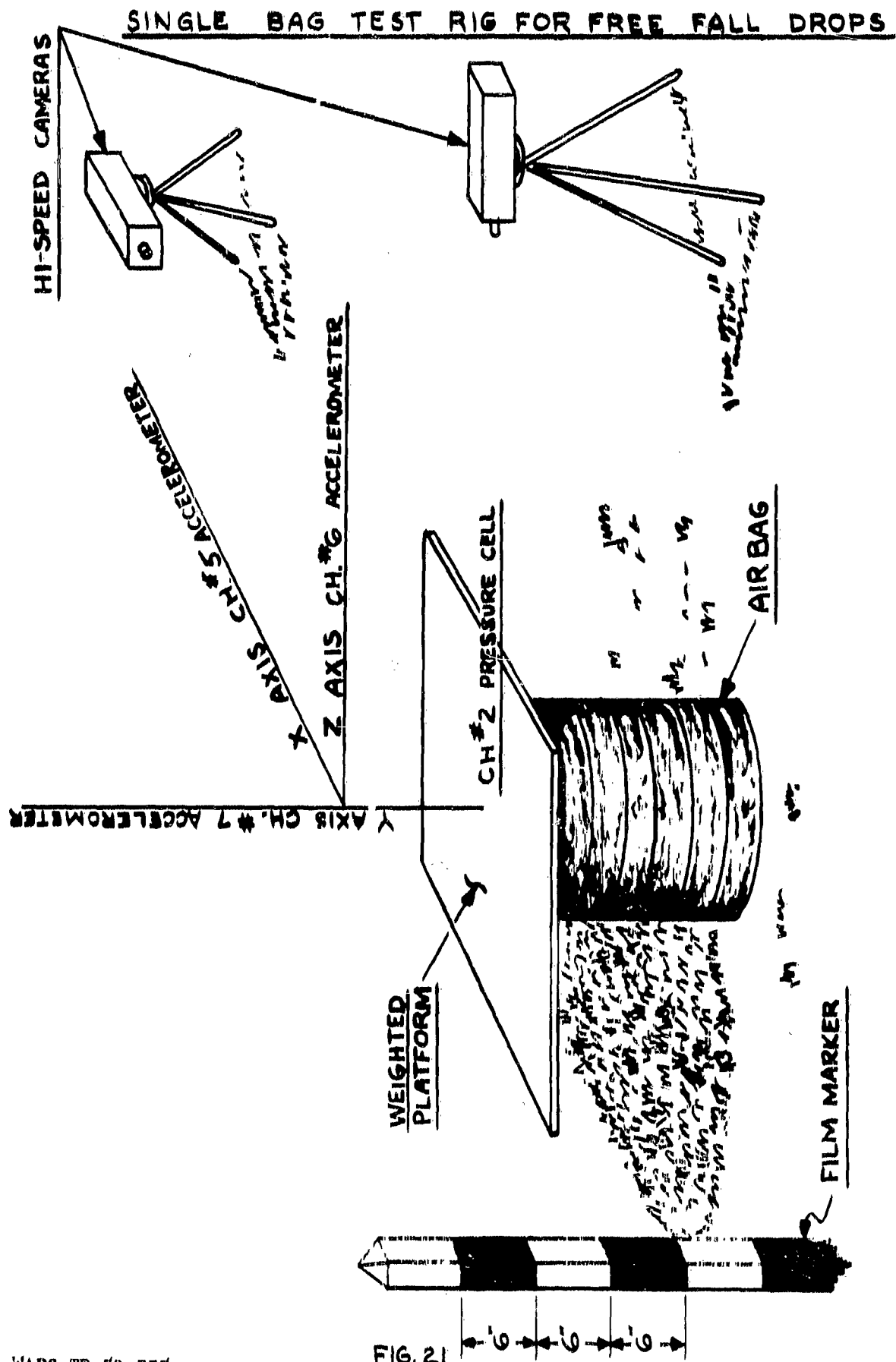
FIG. 21

MULTIPLE BAG TEST RIG FOR FREE FALL DROPS

HI-SPEED CAMERAS

CH.#1, #2, #3, #4 ARE
PRESSURE CELL LOCATIONS.

X AXIS CH.#5 ACCELEROMETER

Z AXIS CH.#6 ACCELEROMETER

Y AXIS CH.#7 ACCELEROMETER

CH.#3

CH.#1

CH.#2

CH.#4

AIRBAG

WEIGHTED
PLATFORM

FILM MARKER
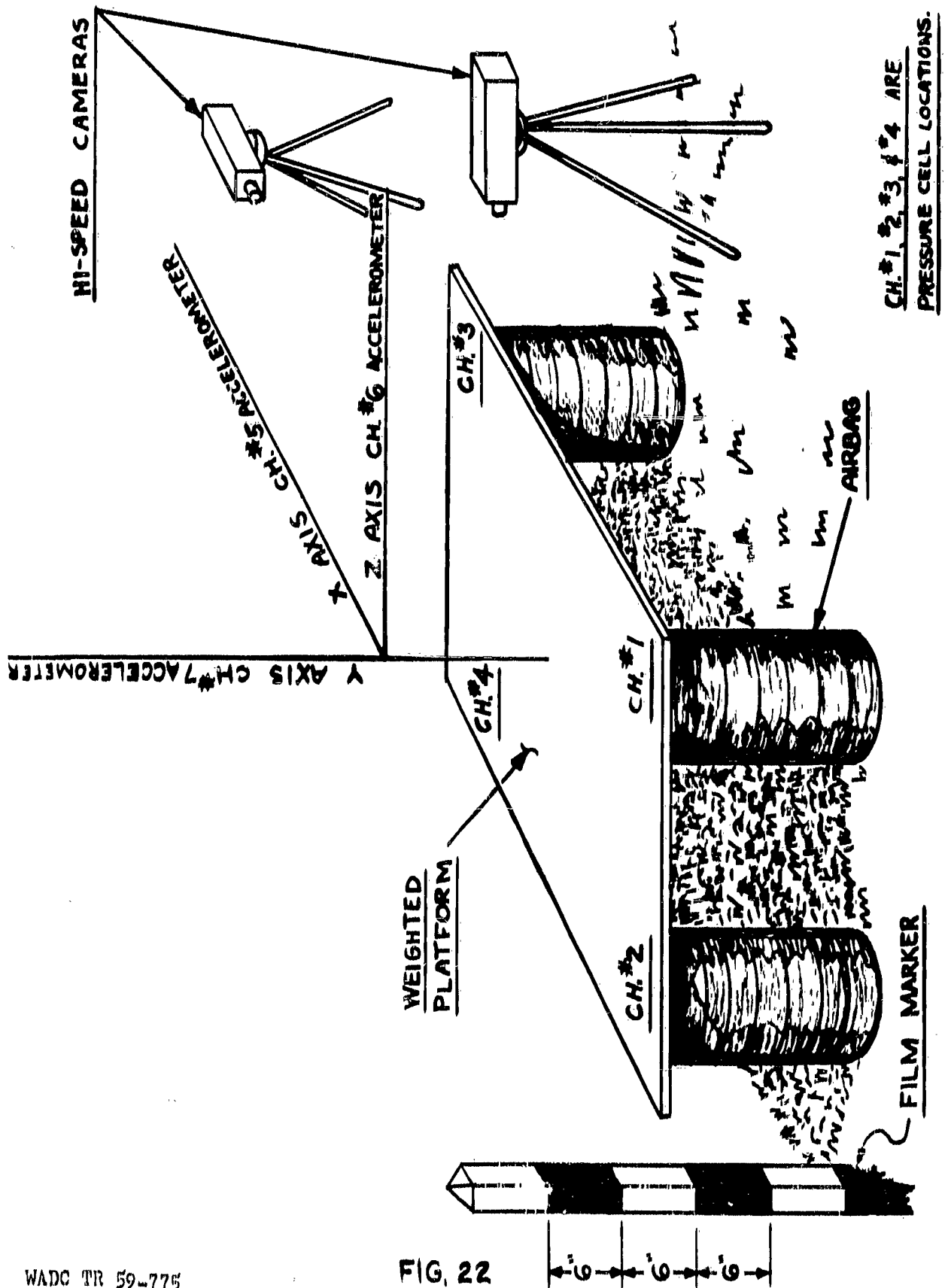
STROKE COMPARISON OF
TESTS # 11 - 12, & 13.
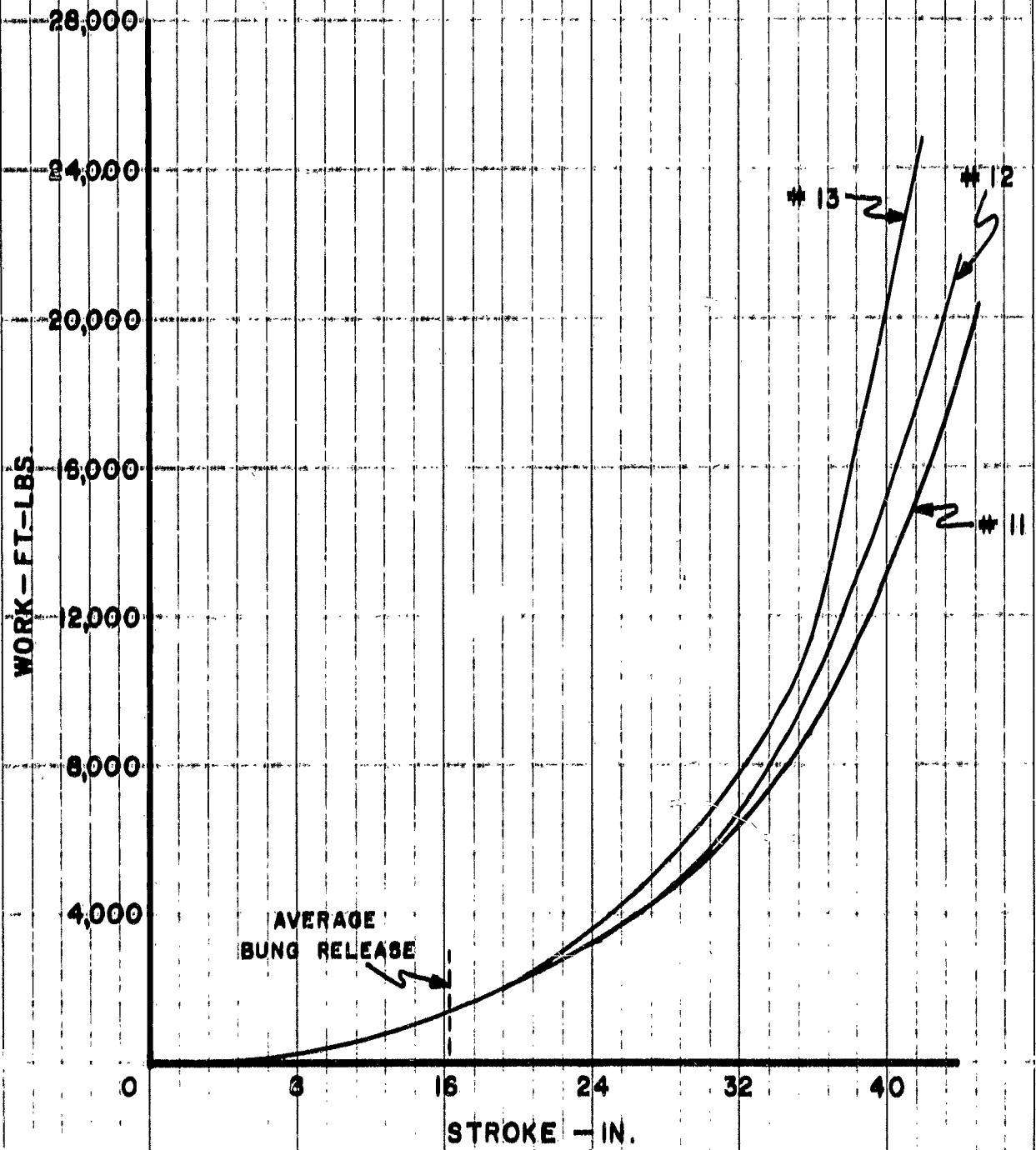
FIG. 23

VELOCITY COMPARISON OF
TESTS # 11, 12, & 13.
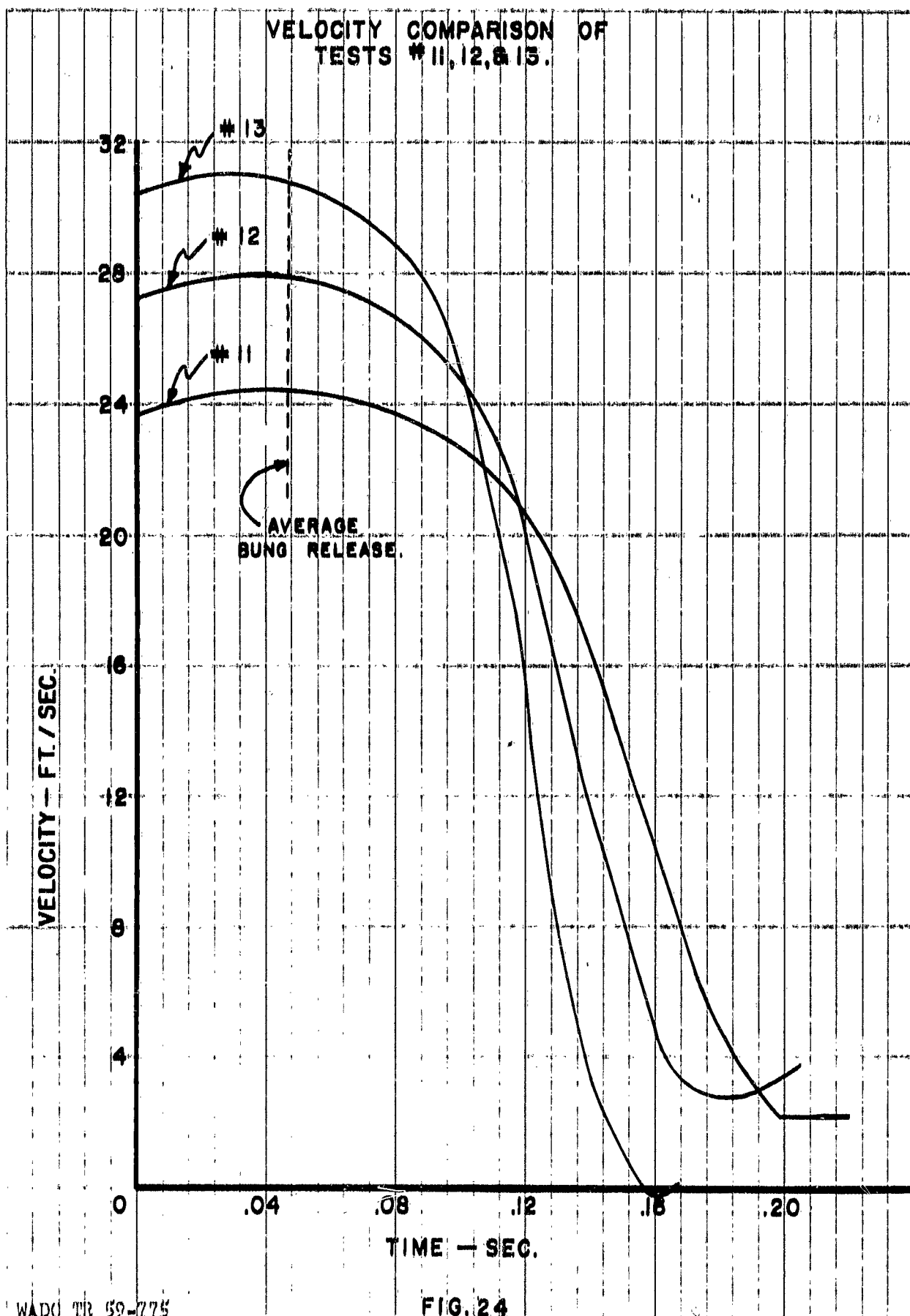
FIG. 24

VELOCITY COMPARISON OF
TESTS #14, 15, & 21

14

15

BUNG
RELEASE

21

VELOCITY — FT. / SEC.

TIME — SEC.
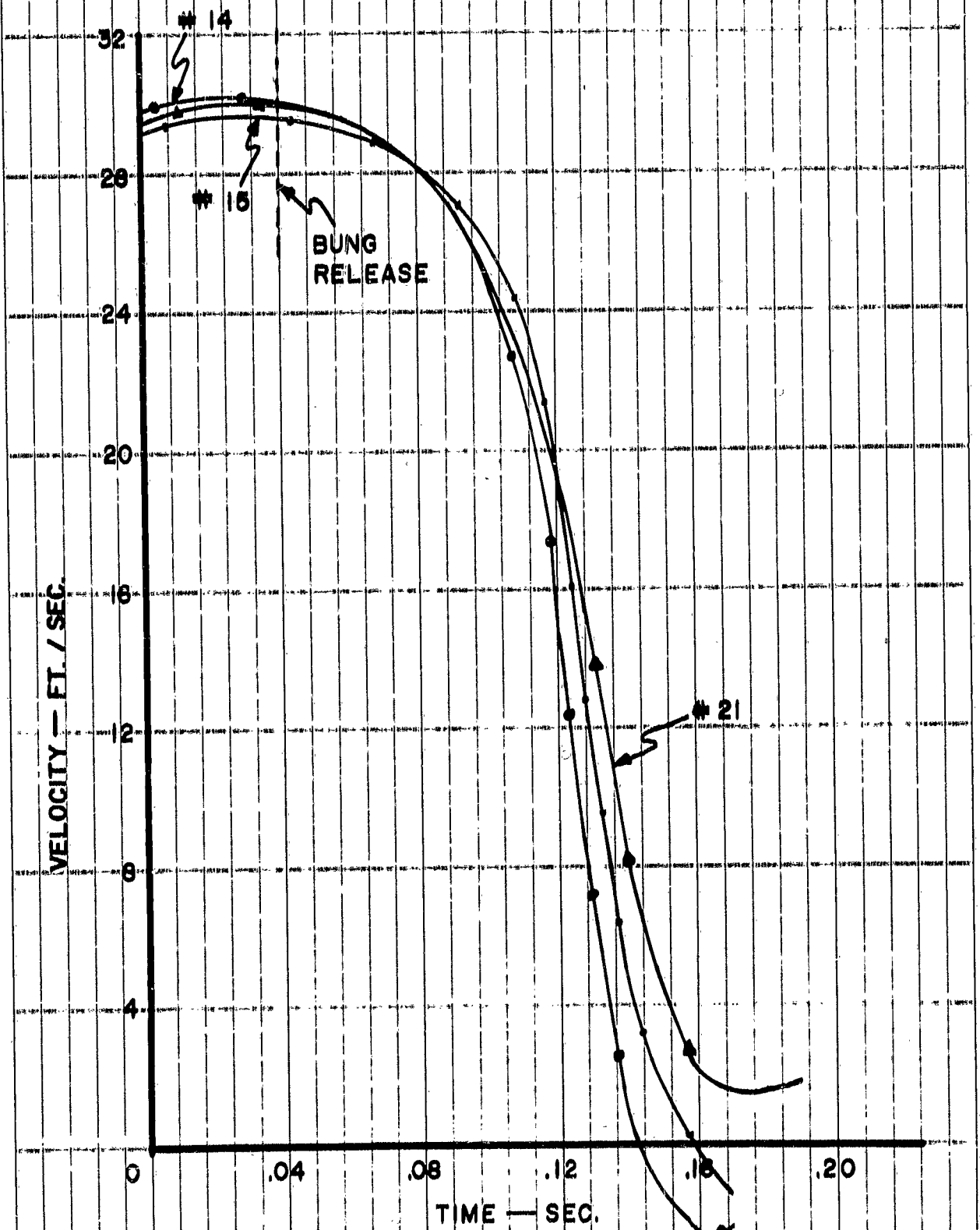
WORK CURVE COMPARISON OF
TESTS #14, 15, & 21
(WEIGHT VARIED)
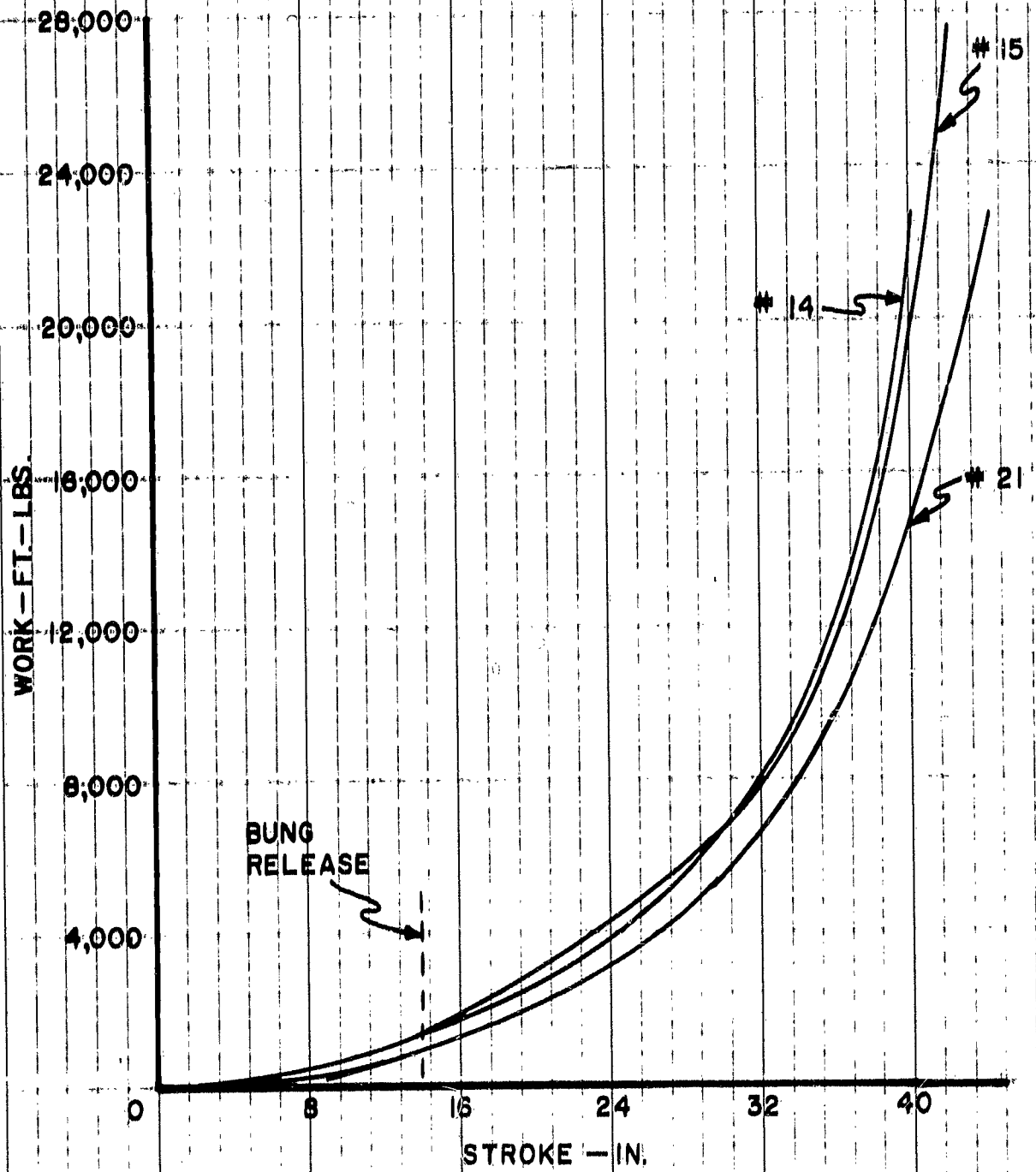
FIG. 26

VELOCITY COMPARISON OF
TESTS # 18, 22, & 23

VELOCITY — FT. / SEC.

TIME — SEC.

22

18

23
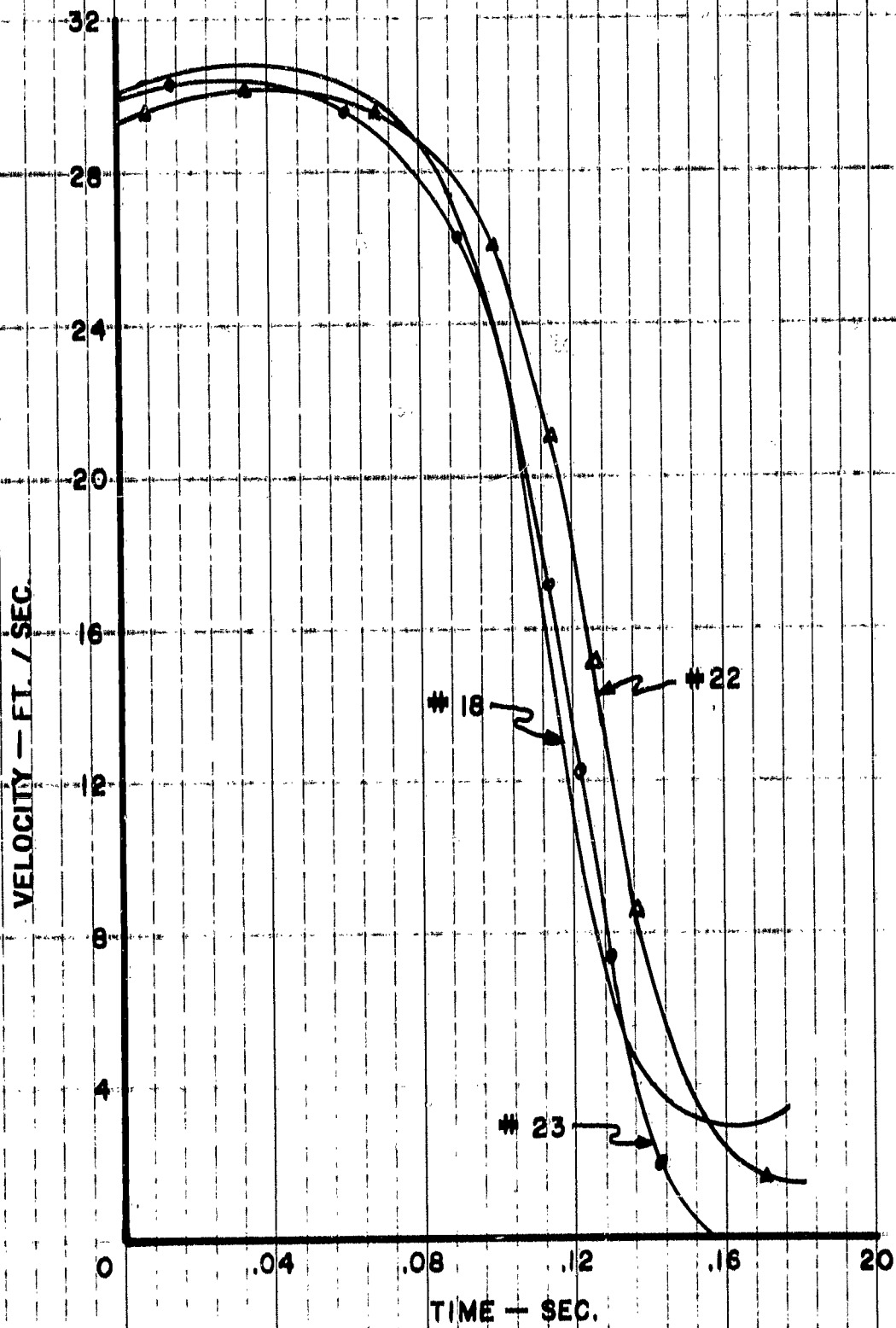
FIG. 27

COMPARISON OF WORK CURVES FOR
TESTS # 18, 22, & 23

18

22

23

WORK—FT—LBS.

24,000

20,000

16,000

12,000

8,000

4,000

0   8   16   24   32   40

STROKE — IN.

COLD TEMPERATURE TORSION

	COMPOUND	$T_{orig.}$
①	70940	176
②	28601	174
③	51932	175
④	52904	173
⑤	52911	173

TEMPERATURE

TWIST

COLD TEMPERATURE TORSION

MAT'L WT & DESC.			T_{orig}
① 8 OZ NEOPRENE	PAINT / NYLON		166
② 82 OZ. XA22AI45	CHEM./ NYLON		175
③ 11.7 OZ. FT 103	CHEM./ NYLON		168
④ 12 OZ. A 328	NEOP./ NYLON		176
⑤ 12 OZ. A 330	NEOP./ NYLON		169

TWIST

TEMPERATURE

FIG. 30

60

COLD TEMPERATURE TORSION

	MAT'L. WT. & DESC.		MAT'L.	Torsion
①	8 OZ.	NEOPRENE	NEOP./NYLON	166
②	82 OZ.	XA22AI45	CHEM./NYLON	175
③	II7 OZ.	FT 103	CHEM./NYLON	168
④	12 OZ	A 328	NEOP./NYLON	176
⑤	12 OZ	A 330	NEOP./NYLON	169
⑥	82 OZ	XA22AI46	RUBBER/NYLON	173
⑦	82 OZ.	XA22AI47	RUBBER/NYLON	172
⑧	82 OZ.	XA22AI48	RUBBER/NYLON	172
⑨	82 OZ.	XA22AI49	RUBBER/NYLON	171

TEMPERATURE ——— °C

TWIST

TEST # 17 CHART # 0941
SINGLE BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAG
W=1385 # D_o=4½" D_p=6" V_o=21.25 FT./SEC.

PRESSURE VS. TIME

PRESSURE — PSIG

TIME — SEC.

WADC TR 59-775

FIG. 32

62

TEST # 17 CHART # 0941
DECELERATION, VELOCITY, STROKE VS. TIME
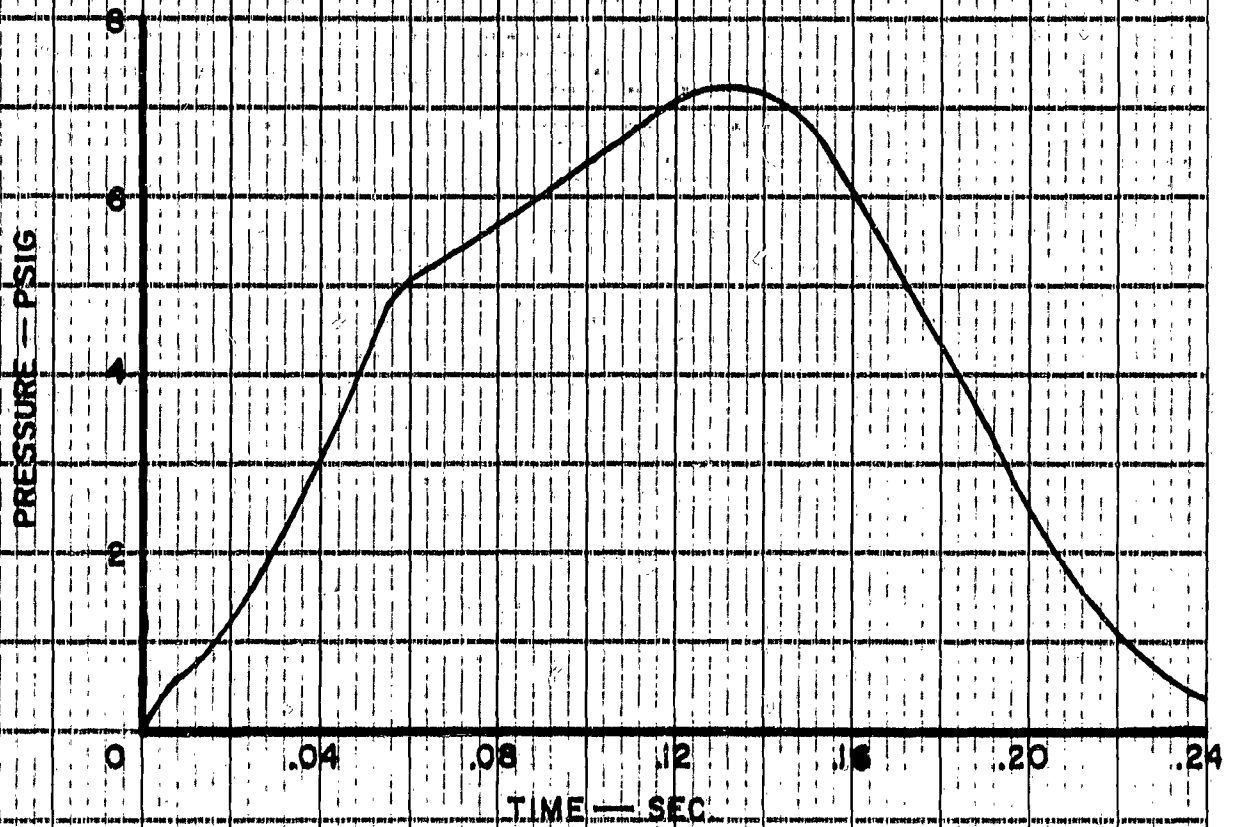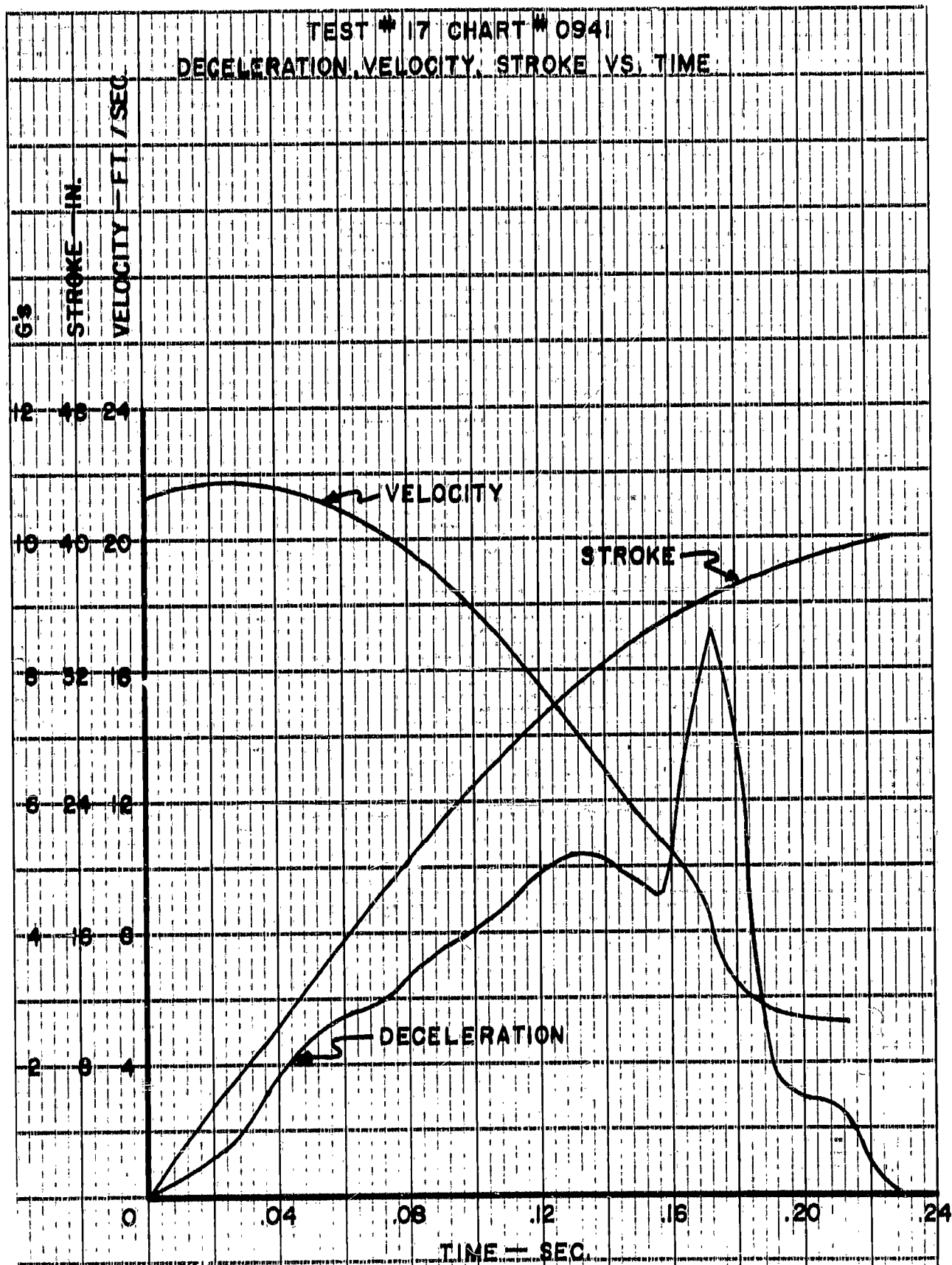
FIG. 33

TEST # 17 CHART # 0941
G's VS STROKE

FIG. 34
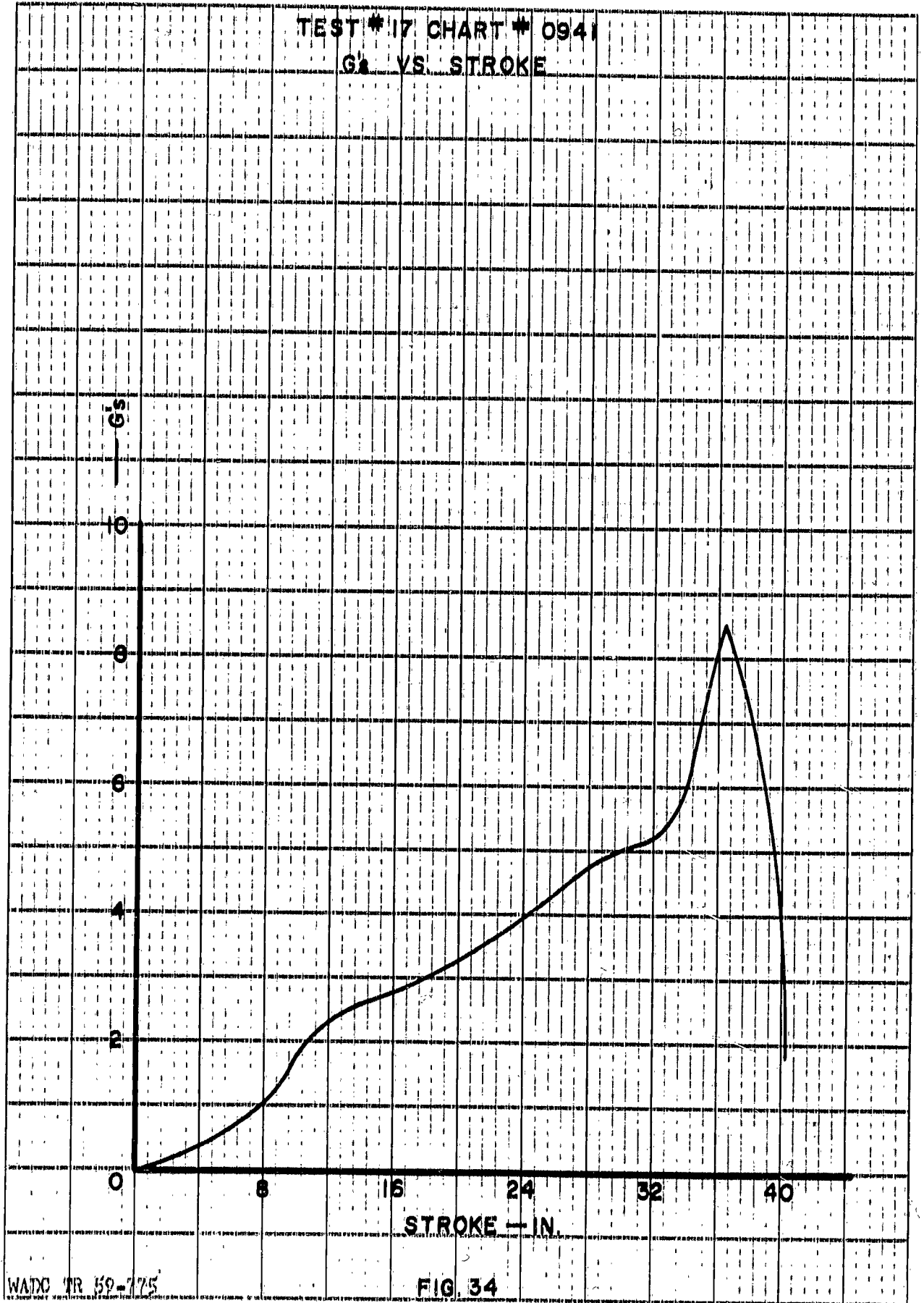
WADC TR 59-775

TEST # 17 CHART # 0941
WORK VS. STROKE

FIG. 35

TEST # II   CHART # 0719
MULTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W = 1550 #/BAG D_s = 4.5" D_p = 6" V_o = 23.6 FT./SEC.
PRESSURE VS. TIME

FIG. 36

TEST # 11   CHART # 0719
DECELERATION, VELOCITY, STROKE, VS. TIME
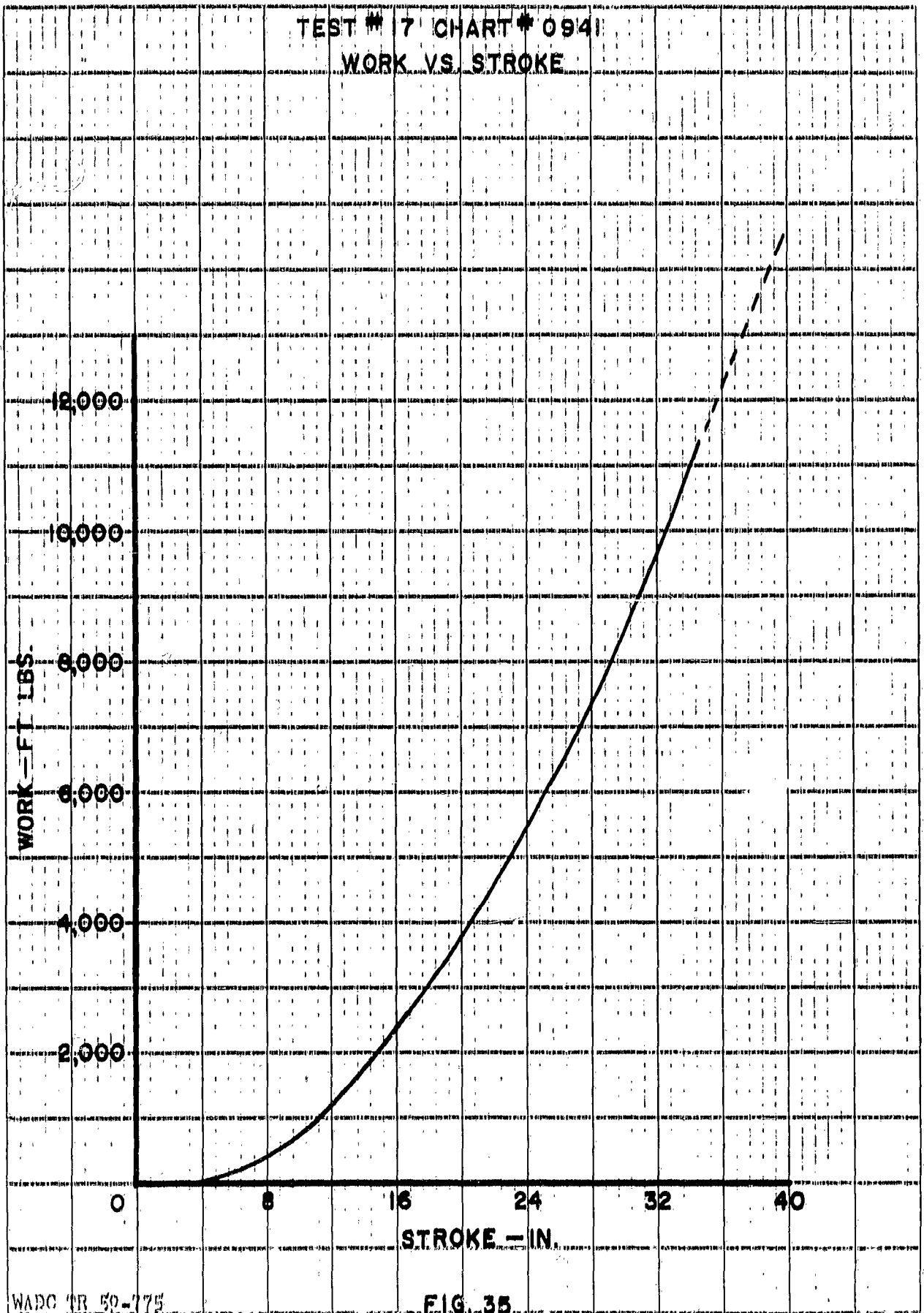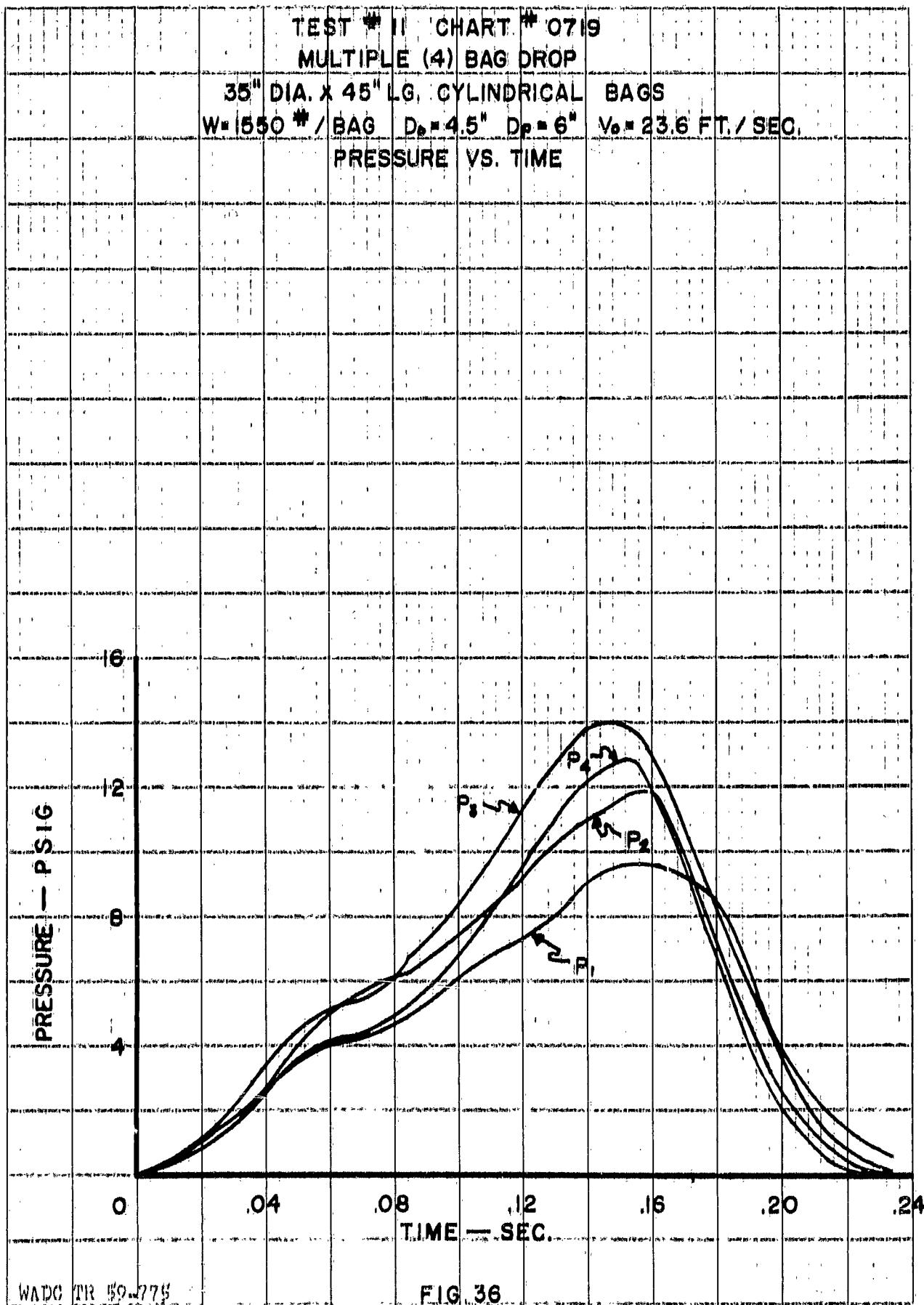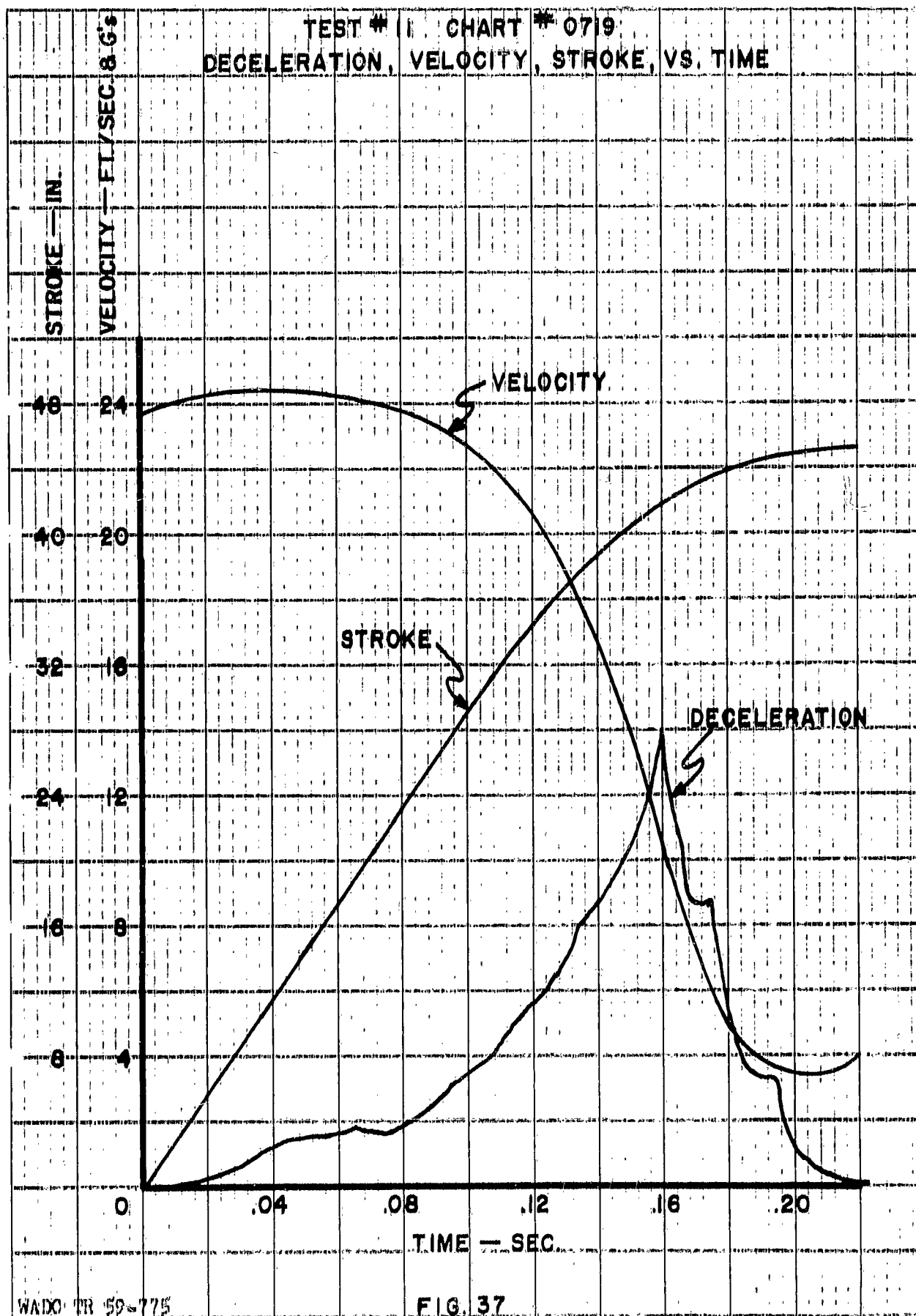
FIG. 37

TEST # 11   CHART # 0719
G's VS STROKE
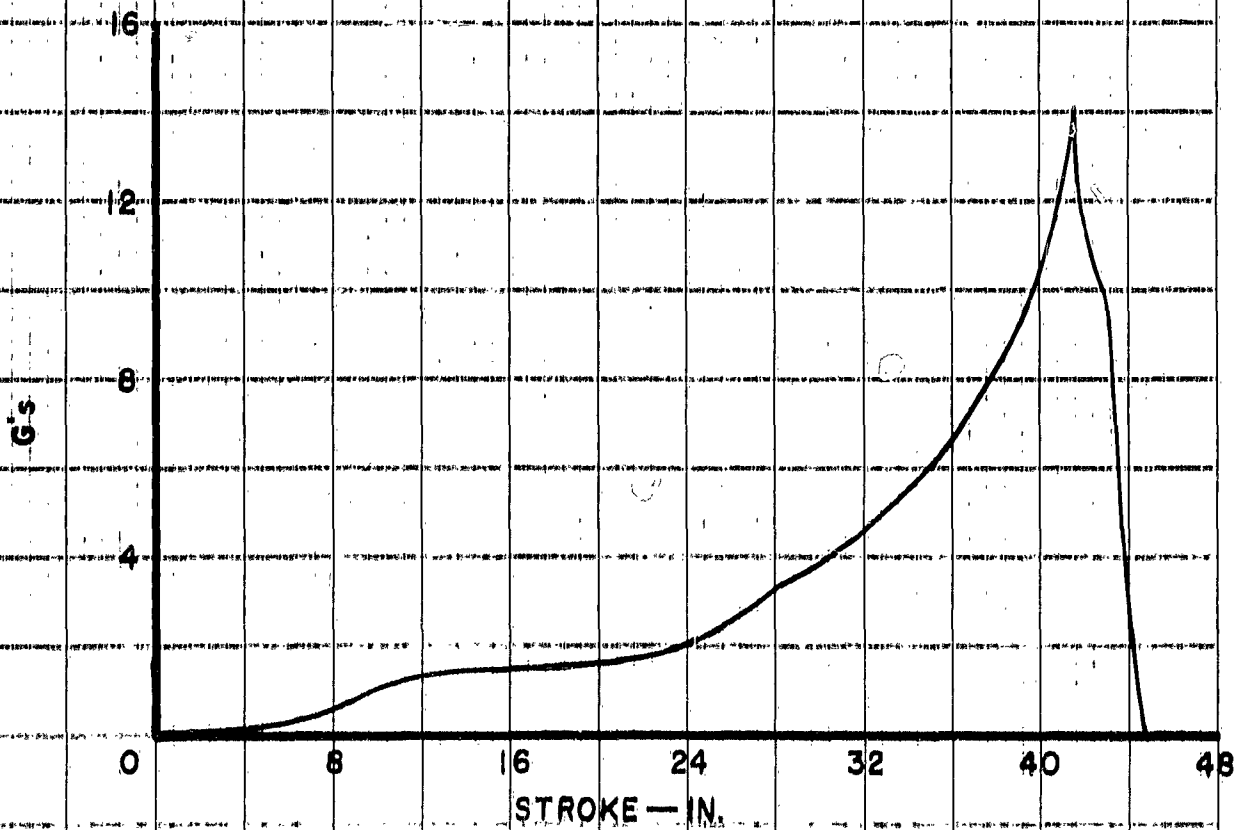
FIG. 38

TEST # II   CHART # 0719
WORK VS. STROKE
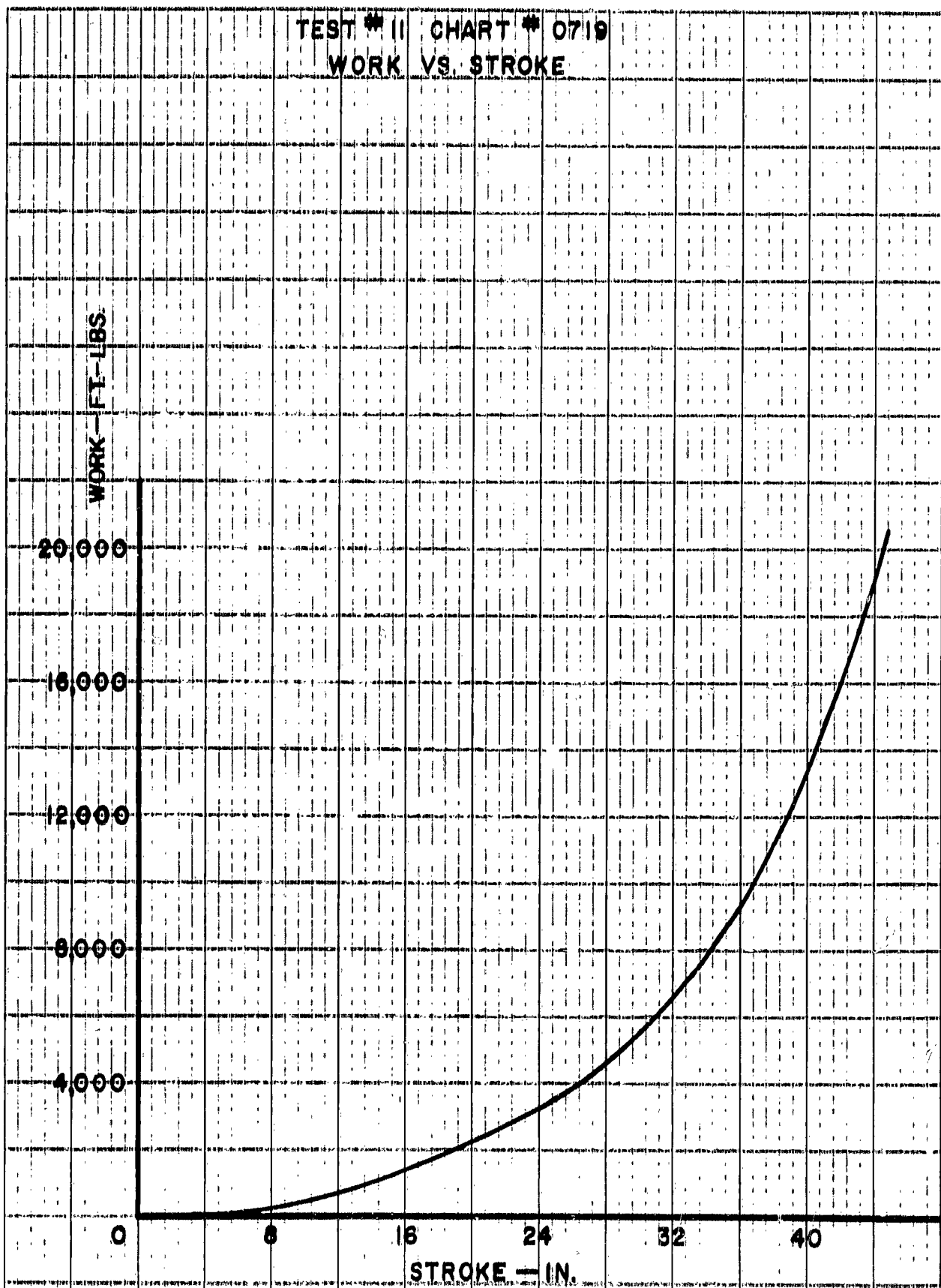
FIG. 39

TEST #12   CHART # 0722
MULTIPLE (4) BAG DROP
35" DIA. x 45" LG. CYLINDRICAL BAGS
W = 1550 #/BAG   D₀ = 4.5"   Dₑ = 6"   V₀ = 27.8 FT./SEC.
PRESSURE VS. TIME

TEST # 12   CHART # 0722
DECELERATION, VELOCITY, STROKE VS. TIME

VELOCITY

STROKE

DECELERATION

TIME — SEC.

WADC TR 52-775

FIG. 41

71

TEST # 12   CHART # 0722
G's   VS. STROKE

G's vertical axis: 20, 16, 12, 8, 4, 0

STROKE — IN. horizontal axis: 0, 8, 16, 24, 32, 40

WADC TR 52-775

FIG. 42

72

TEST # 12 CHART # 0722
WORK VS STROKE

FIG. 43

WADC TR 52-775

TEST #13   CHART # Q723
MULTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W-1550 #/BAG D_c=4.5" D_o=6" V_o=30.27 FT/SEC.
PRESSURE VS TIME

TEST # 13   CHART # 0723
DECELERATION, VELOCITY, STROKE VS TIME
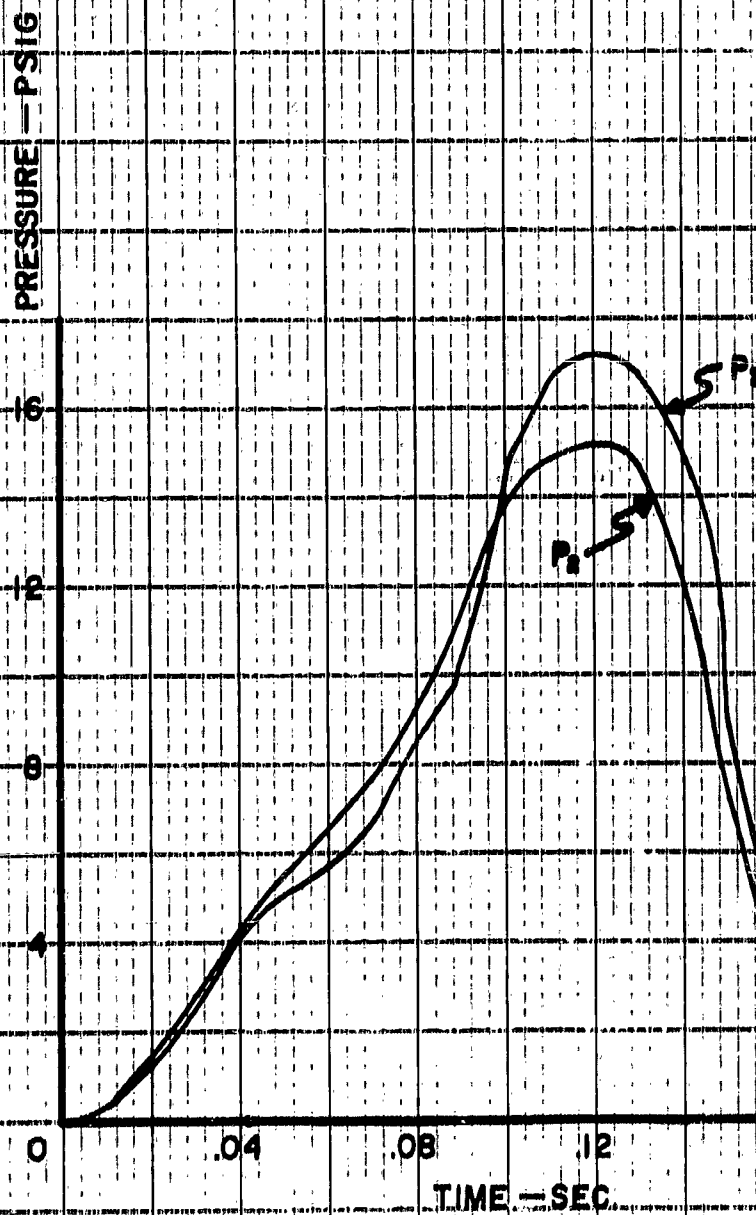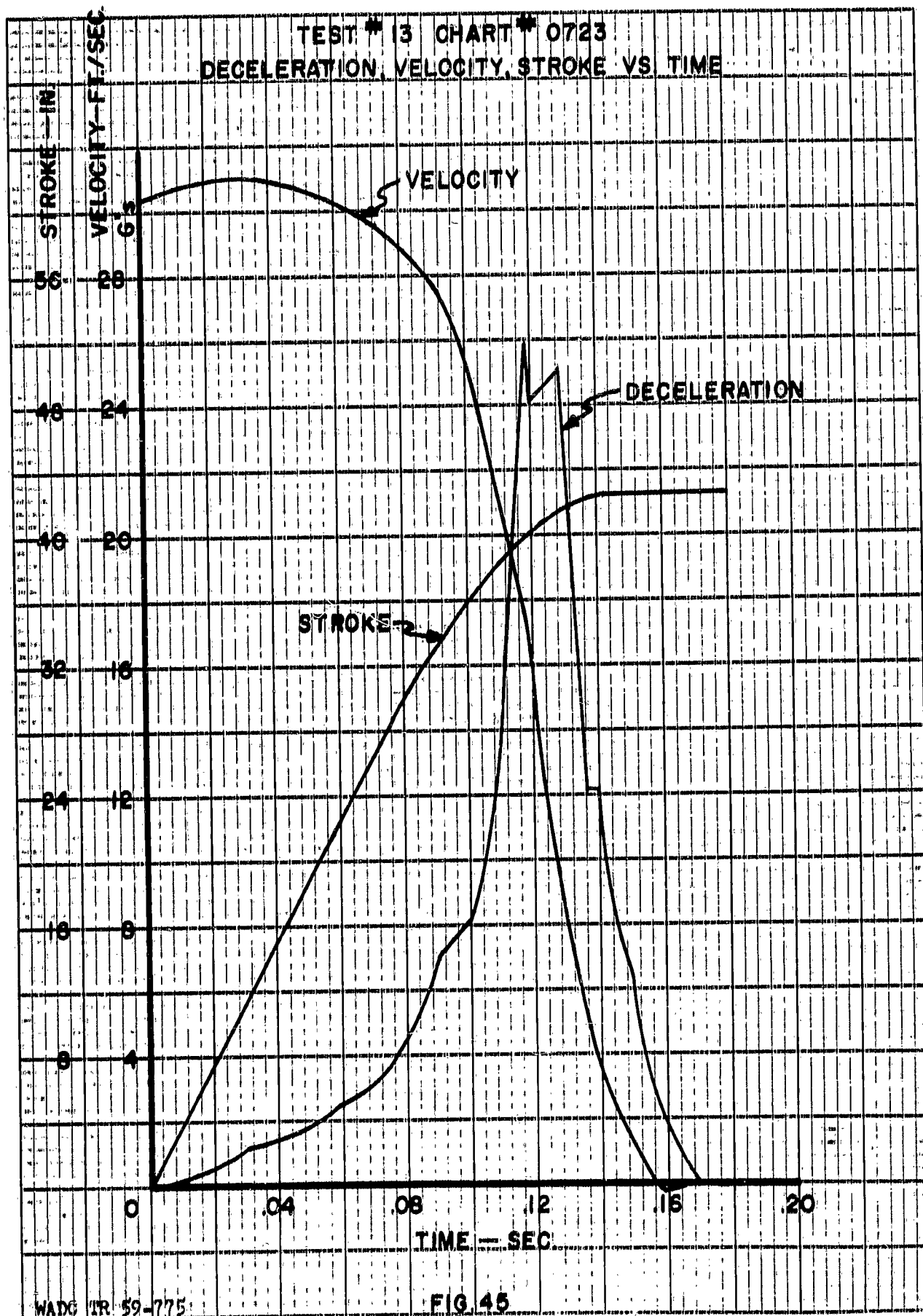
FIG. 45

WADC TR 59-775

75

TEST # 13   CHART # 0723
G's   VS.   STROKE
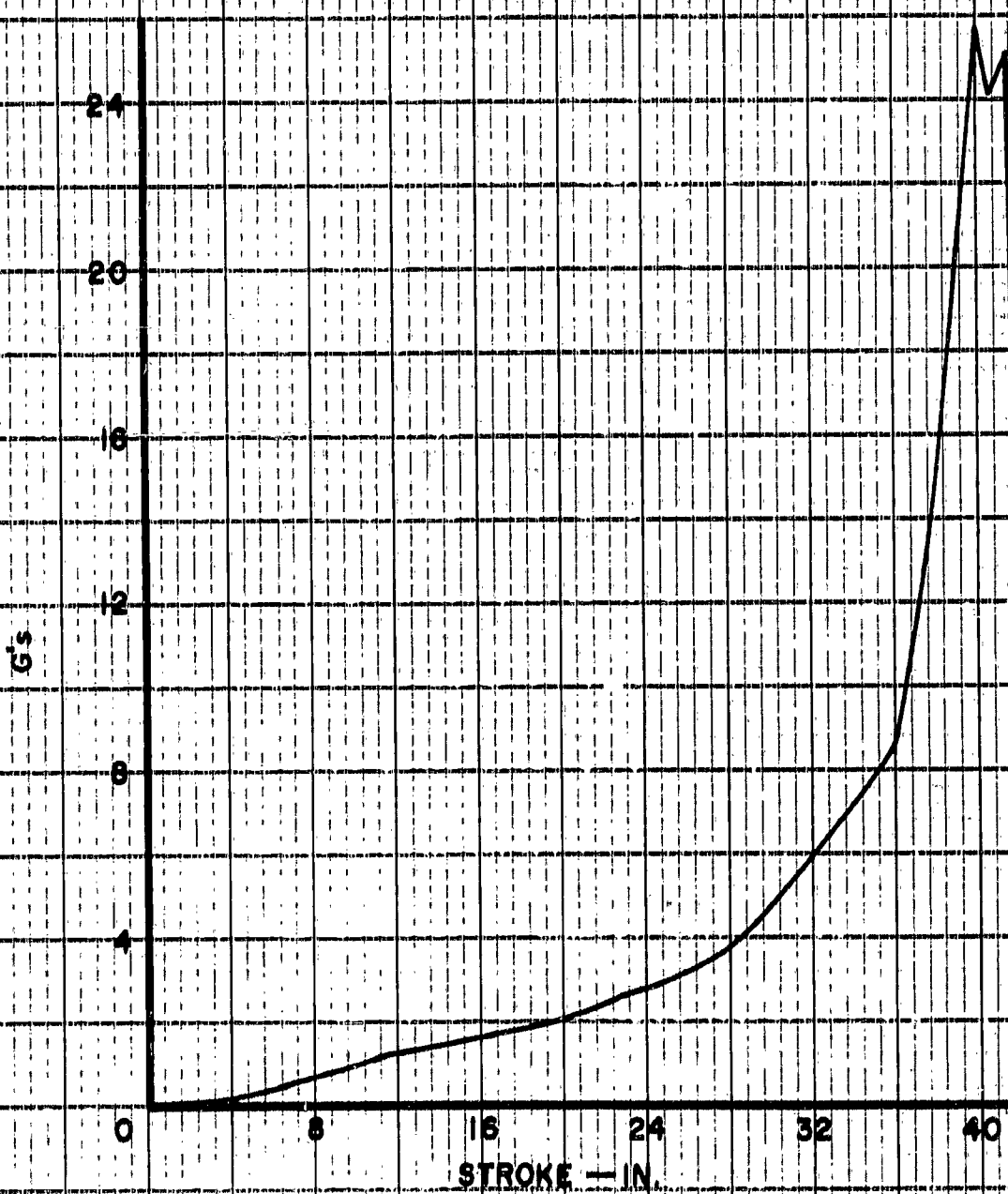
FIG. 46

TEST # 13   CHART # 0723
WORK VS STROKE

FIG. 47

TEST # 14   CHART # 0736
MULTIPLE (4) BAG DROP
35" DIA. x 45" LG. CYLINDRICAL BAGS
W-1550 # /BAG D₀=5.25" Dₚ=6.5" V₀=29.79 FT./SEC.
PRESSURE VS. TIME

PRESSURE — PSIG

P₃
P₂
P₁
P₄

0   .04   .08   .12   .16   .20
TIME — SEC.

TEST #14 CHART #0736
DECELERATION, VELOCITY, STROKE VS TIME

FIG. 49

WADC TR 59-775

TEST #14 CHART #0736
G's VS. STROKE
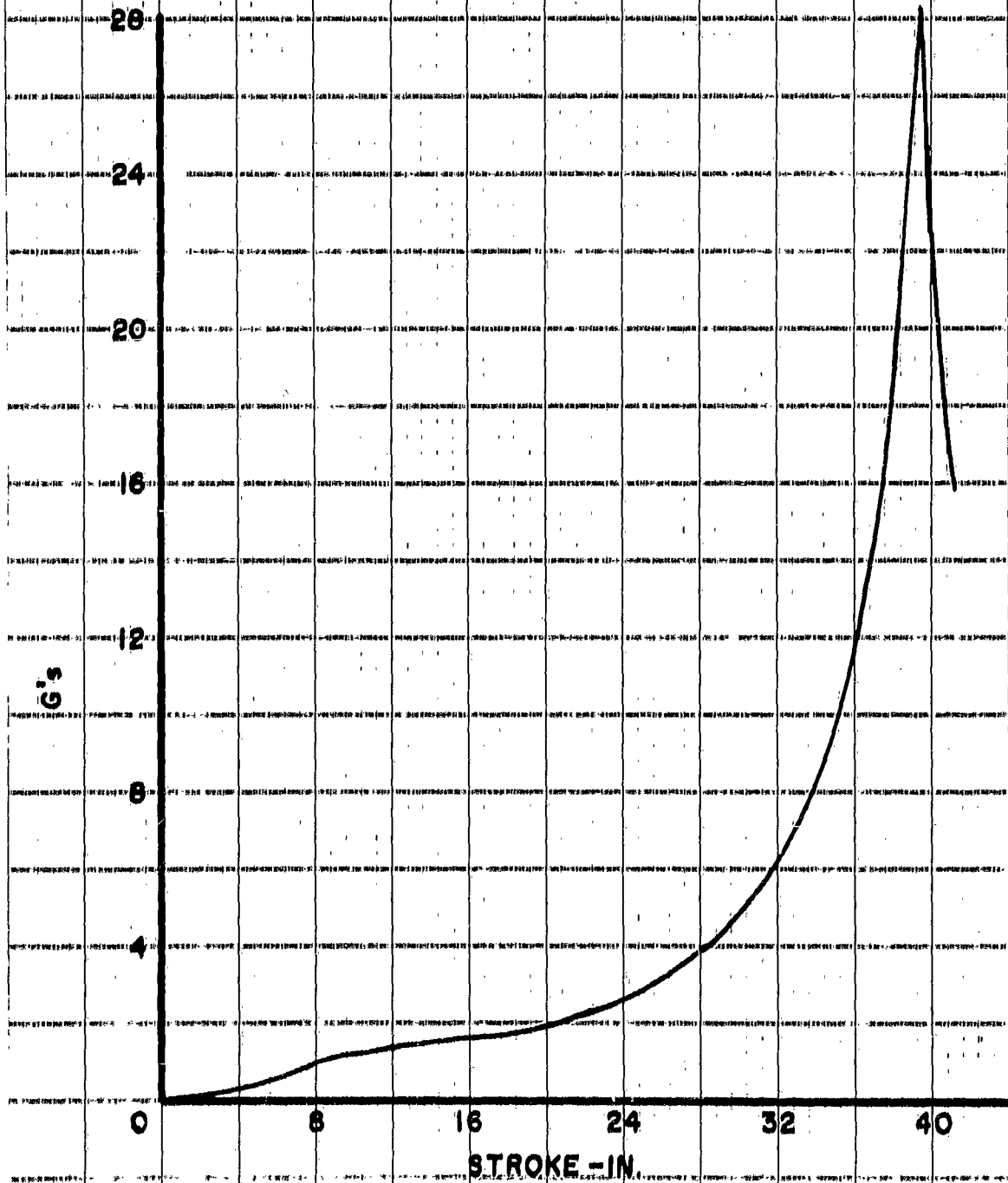
WADC TR 50-775

FIG.50

TEST #14   CHART # 0736
WORK VS. STROKE
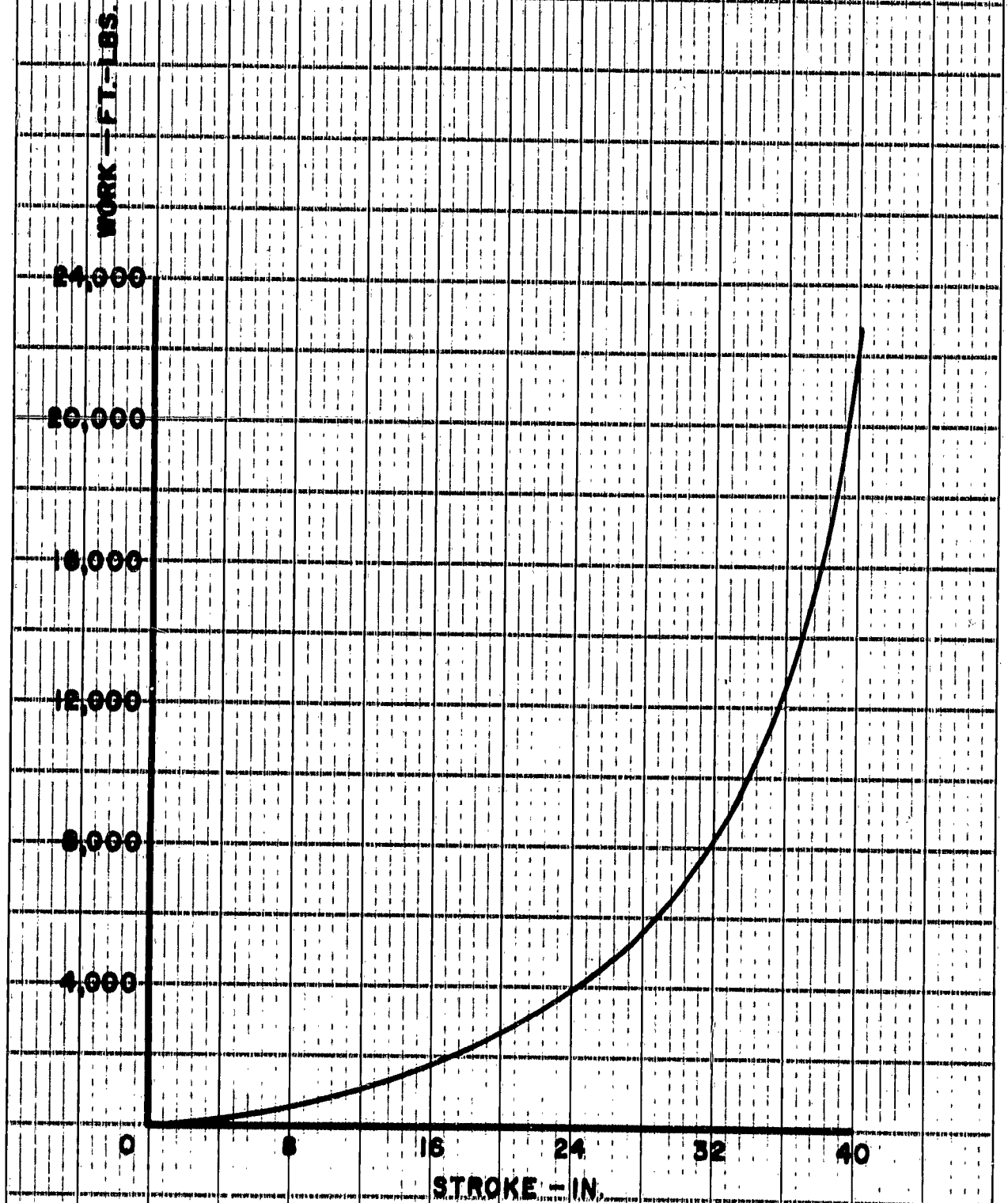
FIG. 51

TEST #15   CHART #0737
MULTIPLE (4)BAG DROP
35"DIA. X 45"LG. CYLINDRICAL BAGS
W=1850#/BAG D₀=5.25" D₈=6.5" V₀=29.14 FT./SEC.
PRESSURE VS. TIME
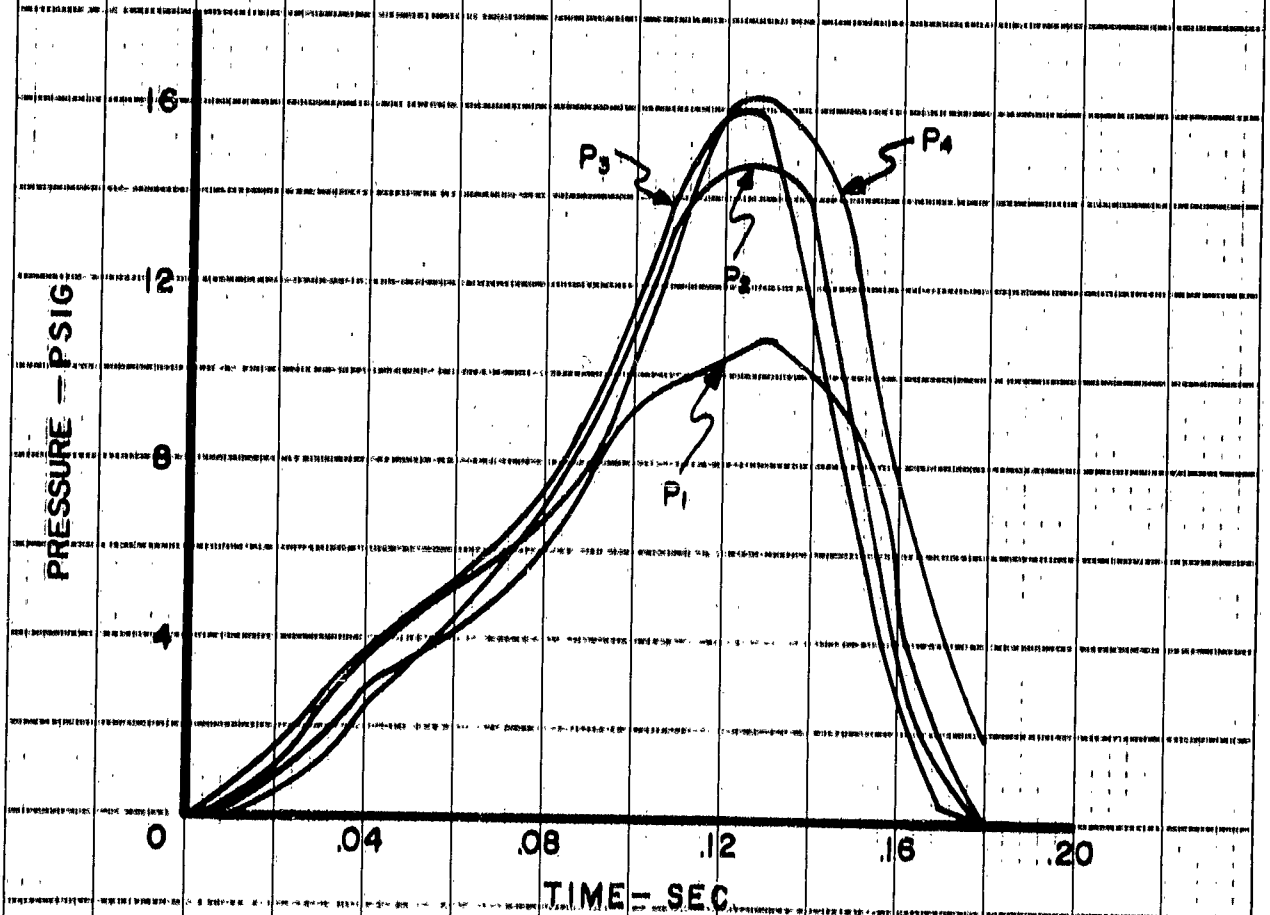
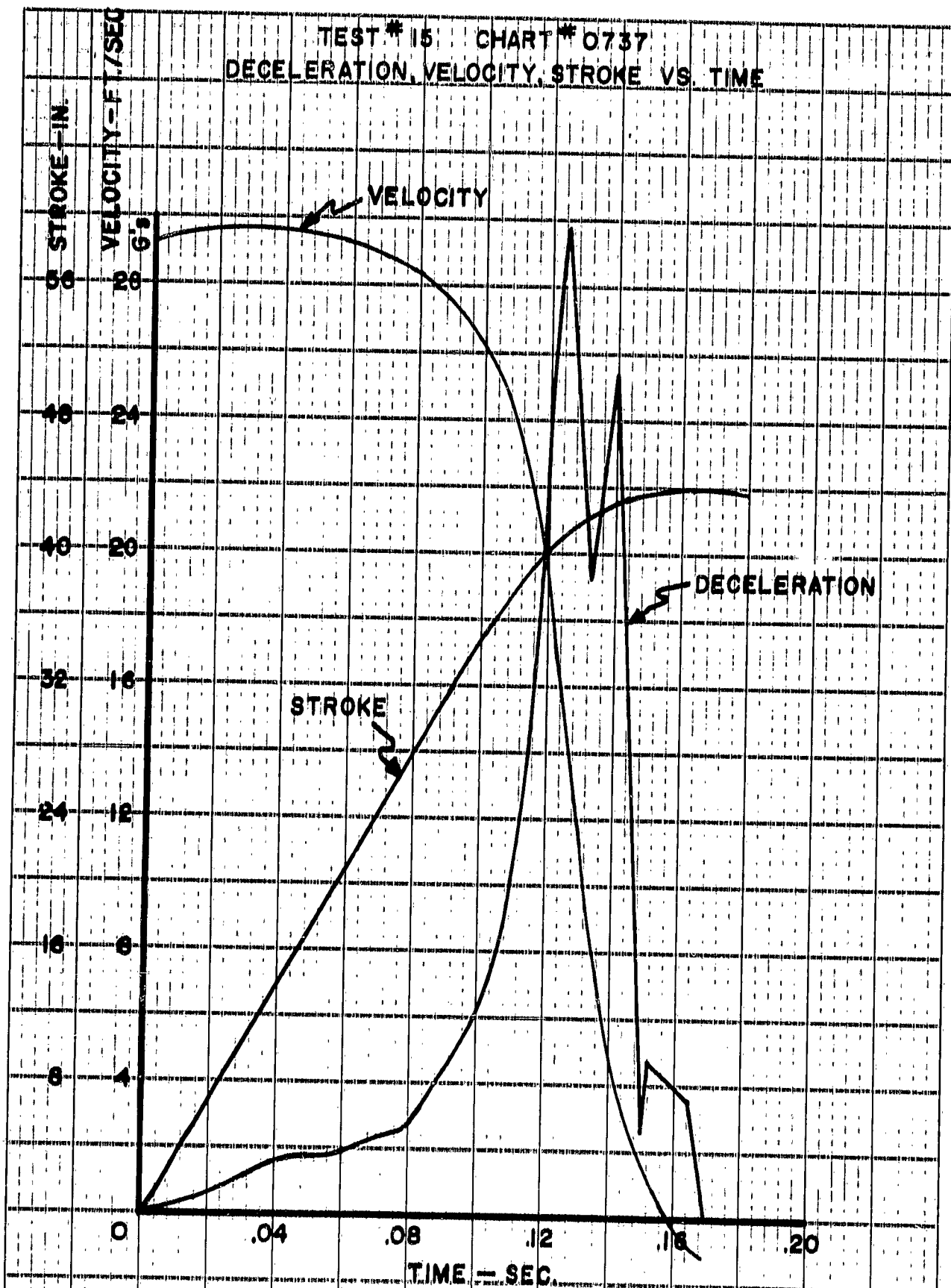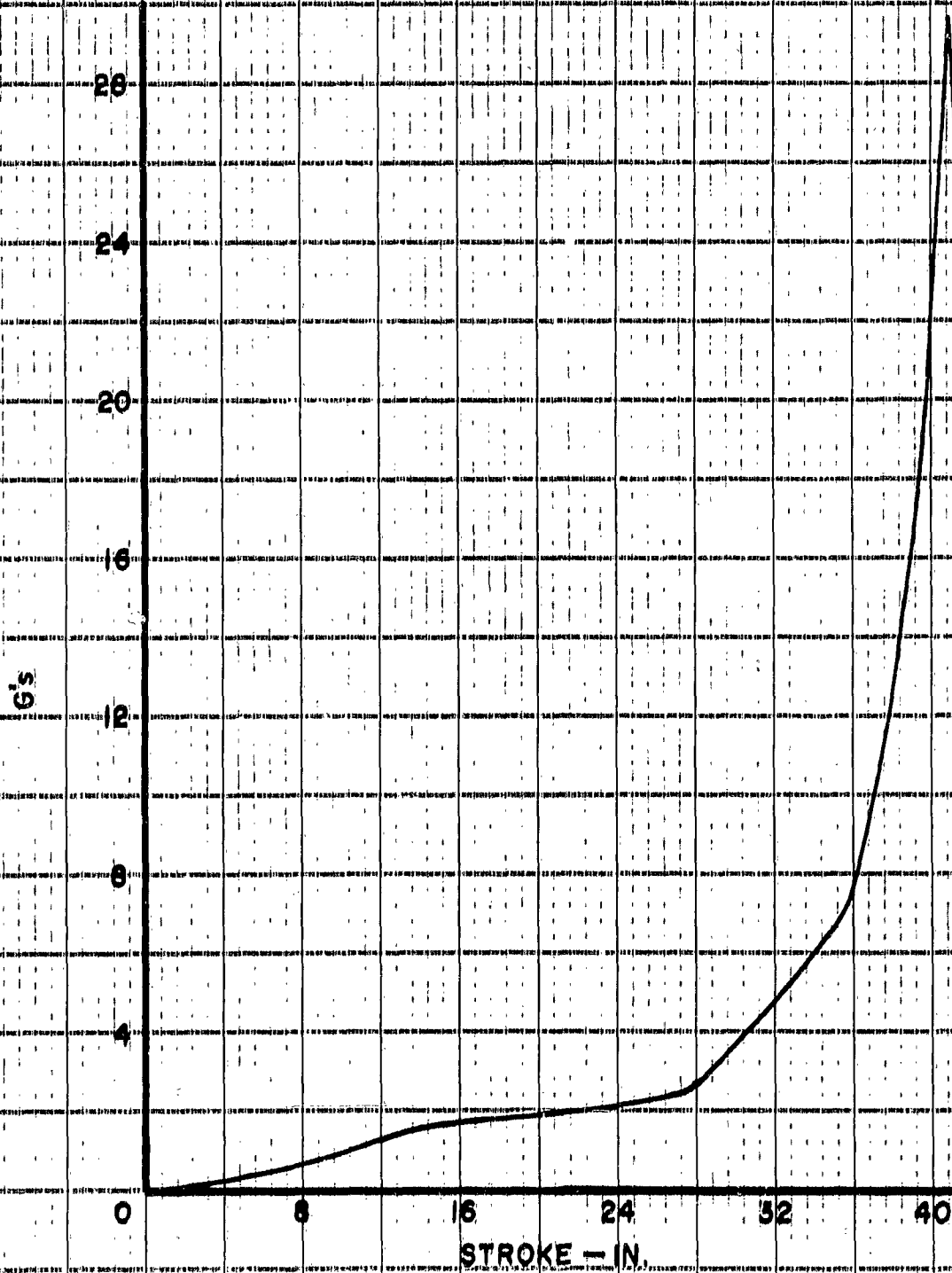WADC TR 59-775   FIG.52

82

TEST #15   CHART #0737
DECELERATION, VELOCITY, STROKE VS. TIME

VELOCITY

DECELERATION

STROKE

TIME — SEC.

WADC TR 59-775

FIG. 53
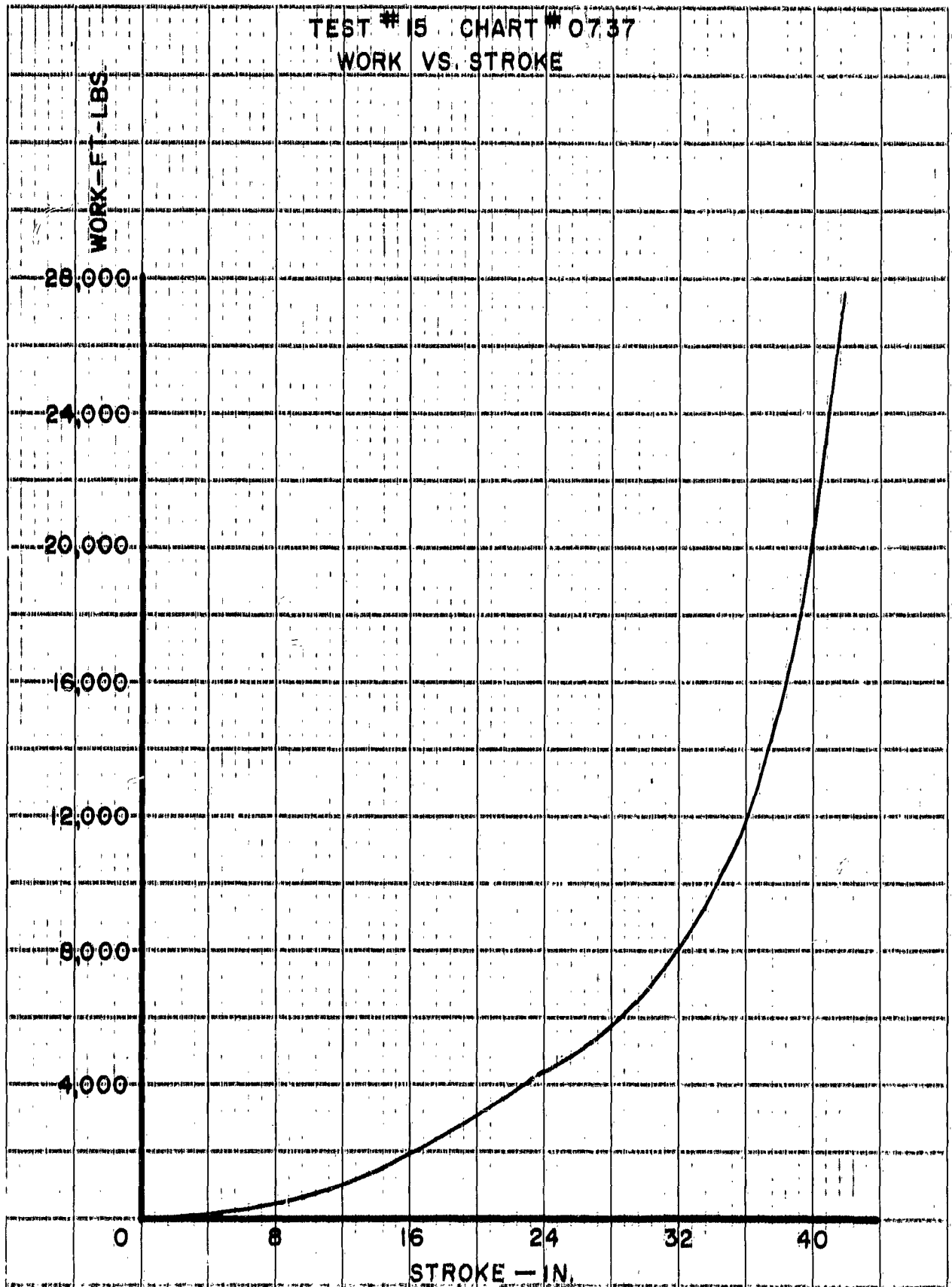
TEST #15   CHART # 0737
G's VS. STROKE

FIG. 54
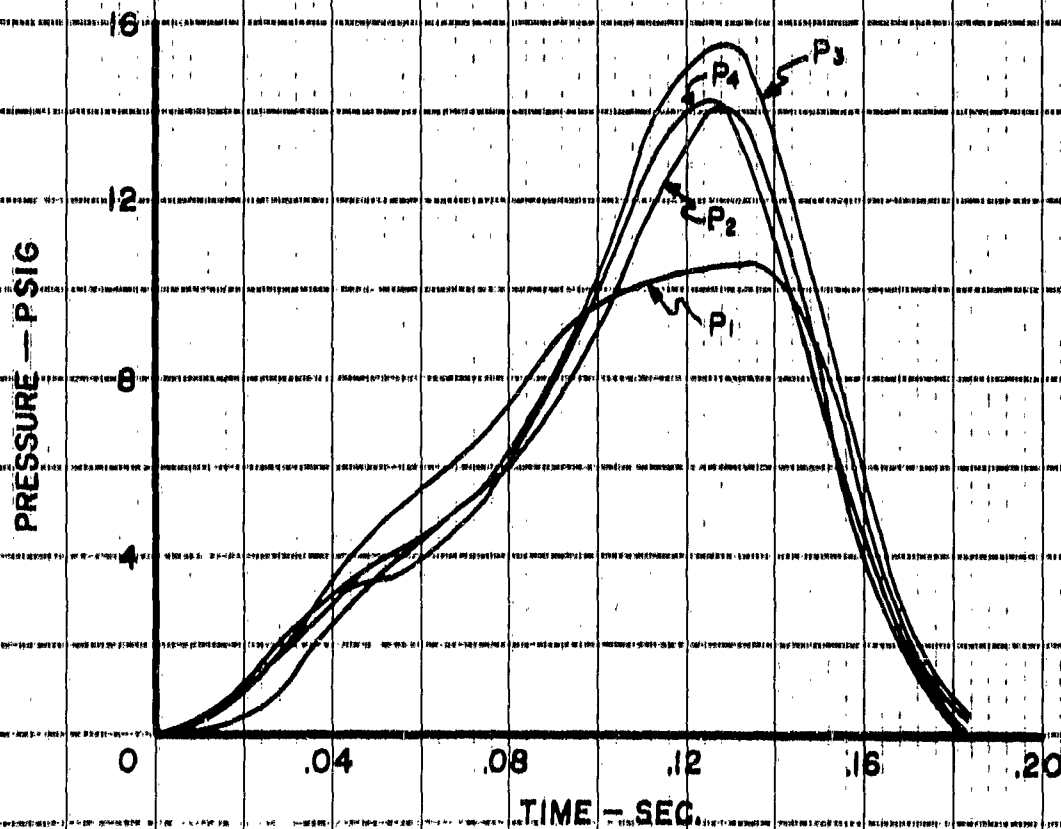
TEST #15   CHART # 0737
WORK VS STROKE

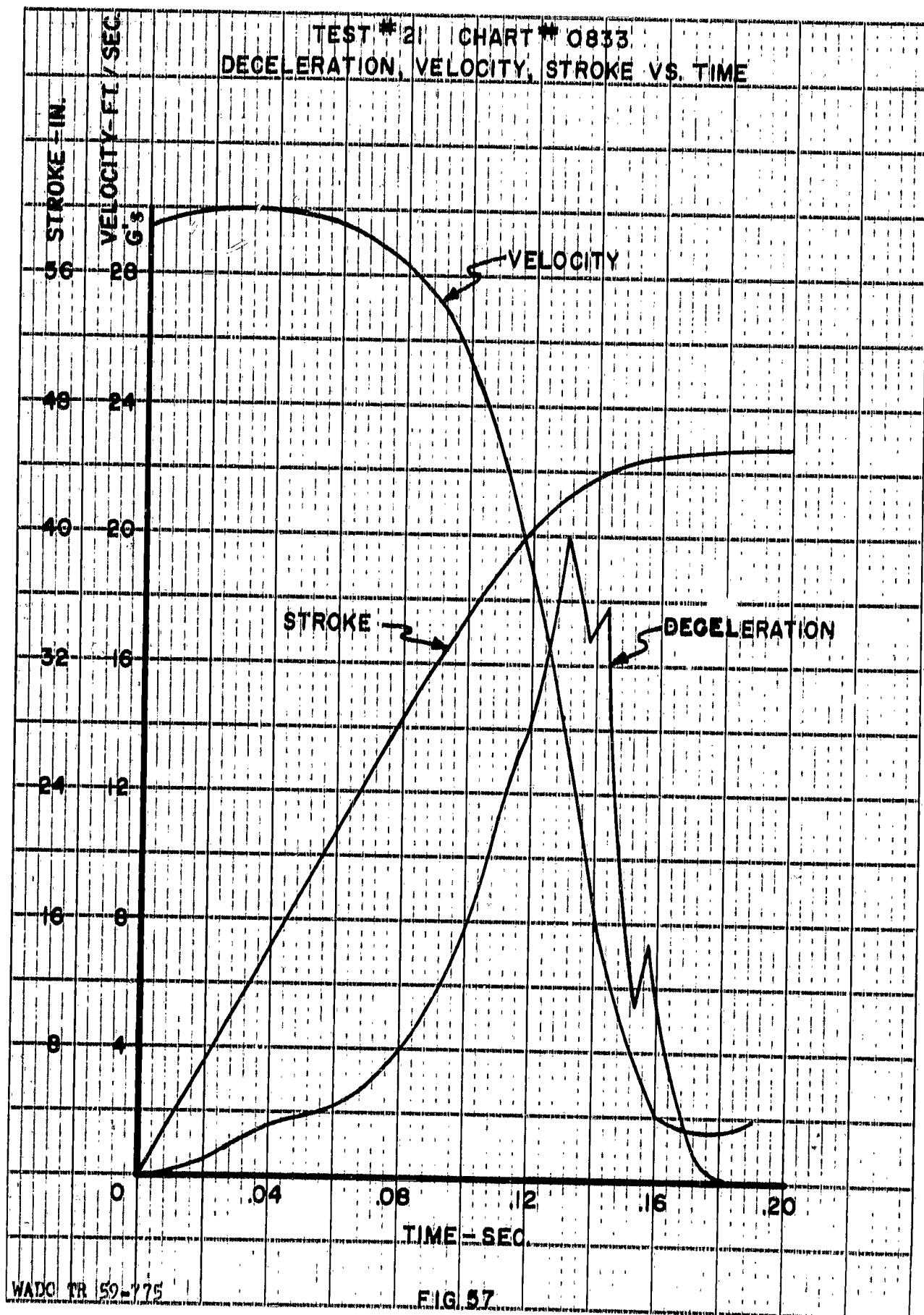FIG. 55

TEST #21   CHART # 0833
MULTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W=1350 #/BAG Dₐ=5.25" Dₚ=5.5" V₀=29.27 FT./SEC.
PRESSURE VS. TIME

FIG. 56

TEST # 21   CHART # 0833
DECELERATION, VELOCITY, STROKE VS. TIME

VELOCITY

STROKE

DECELERATION

TEST # 21   CHART # 0833
G's VS. STROKE
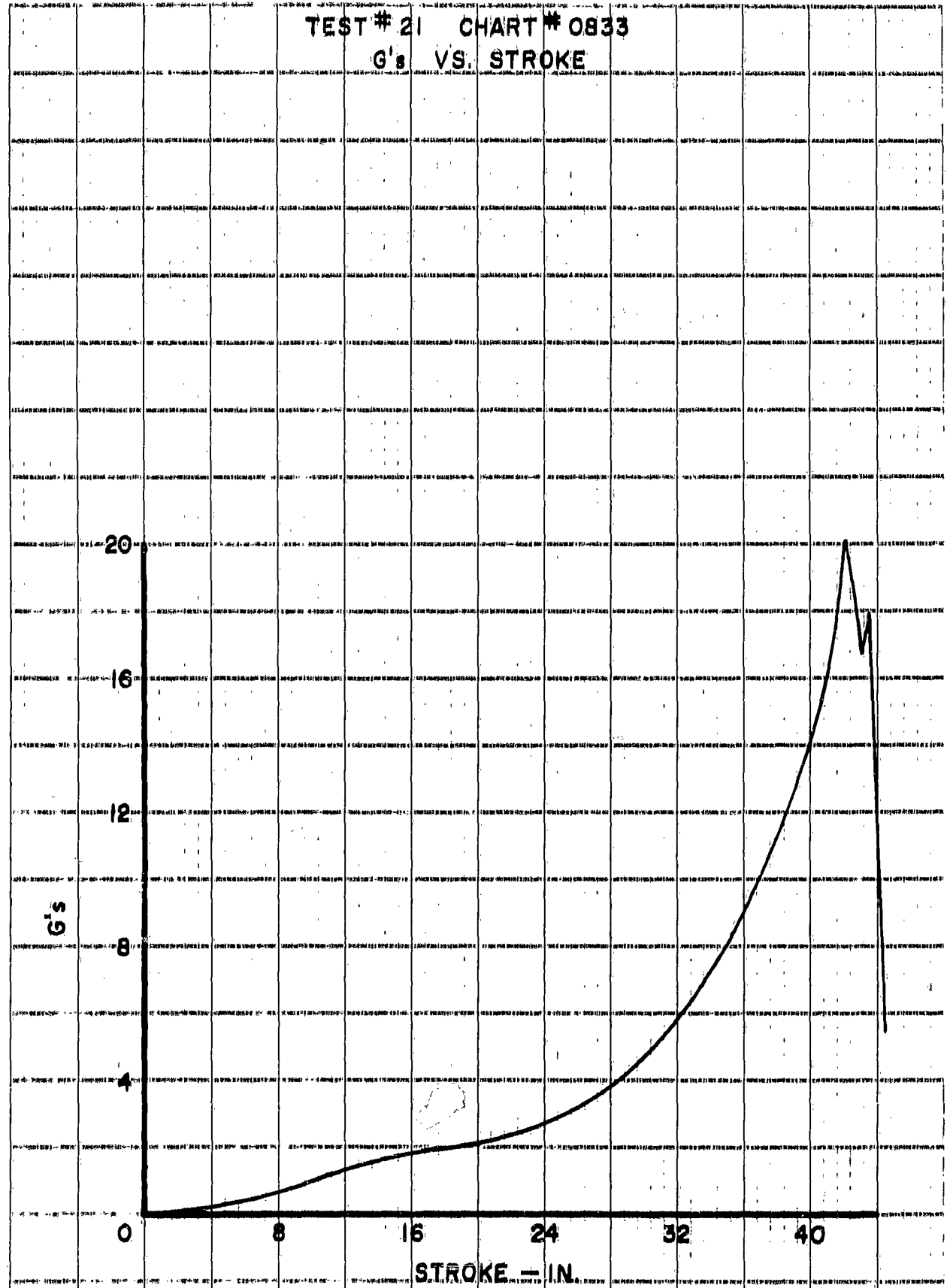
TEST # 21   CHART # 0833
WORK VS. STROKE

WORK — FT.— LBS.
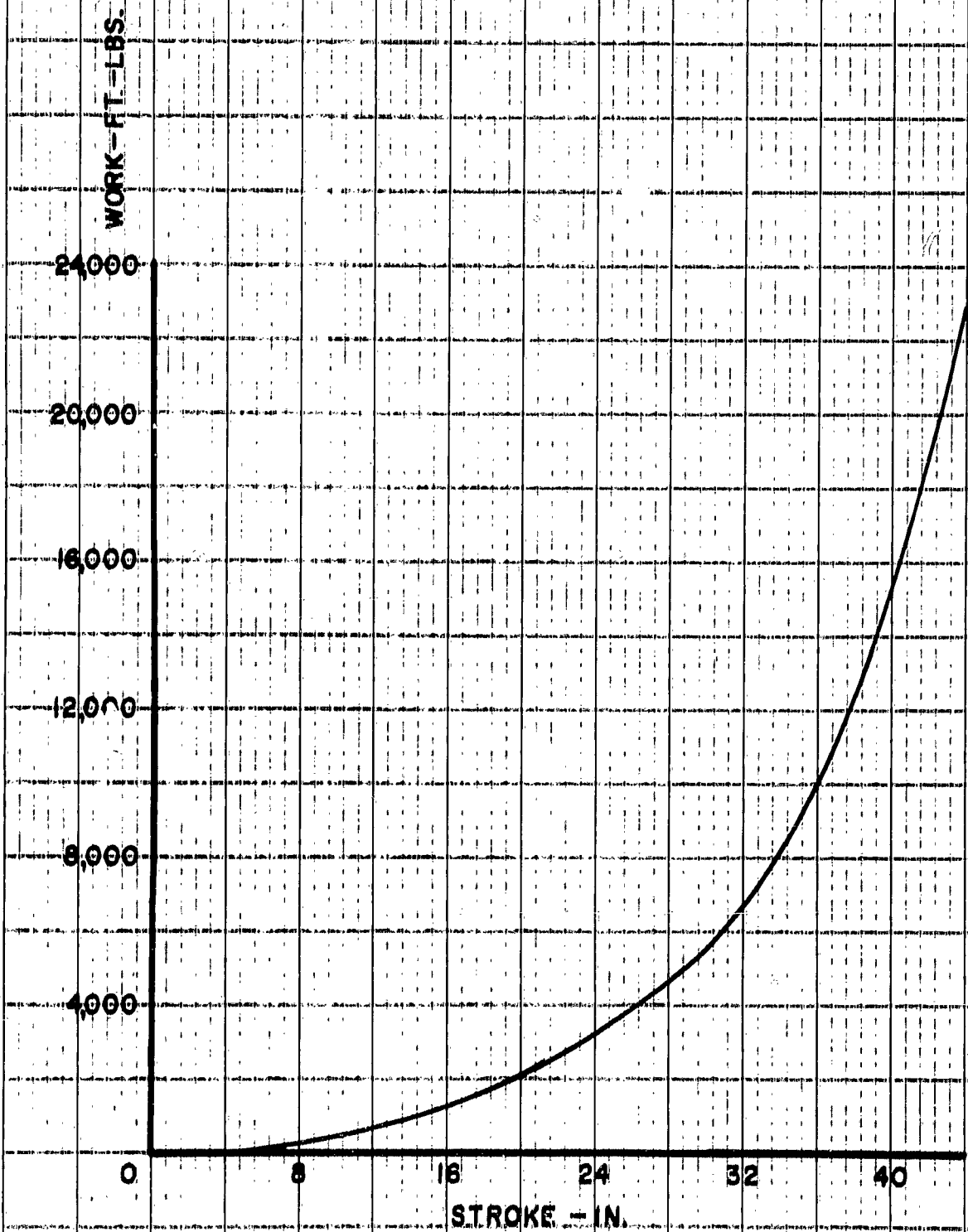
STROKE — IN.

TEST # IB   CHART # 0804
MULTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W = 1350 #/BAG D₀ = 4.5" D₀ = 6" V₀ = 29.85 FT./SEC.
PRESSURE VS. TIME

TEST # 18   CHART # 0804
DECELERATION, VELOCITY, STROKE, VS. TIME
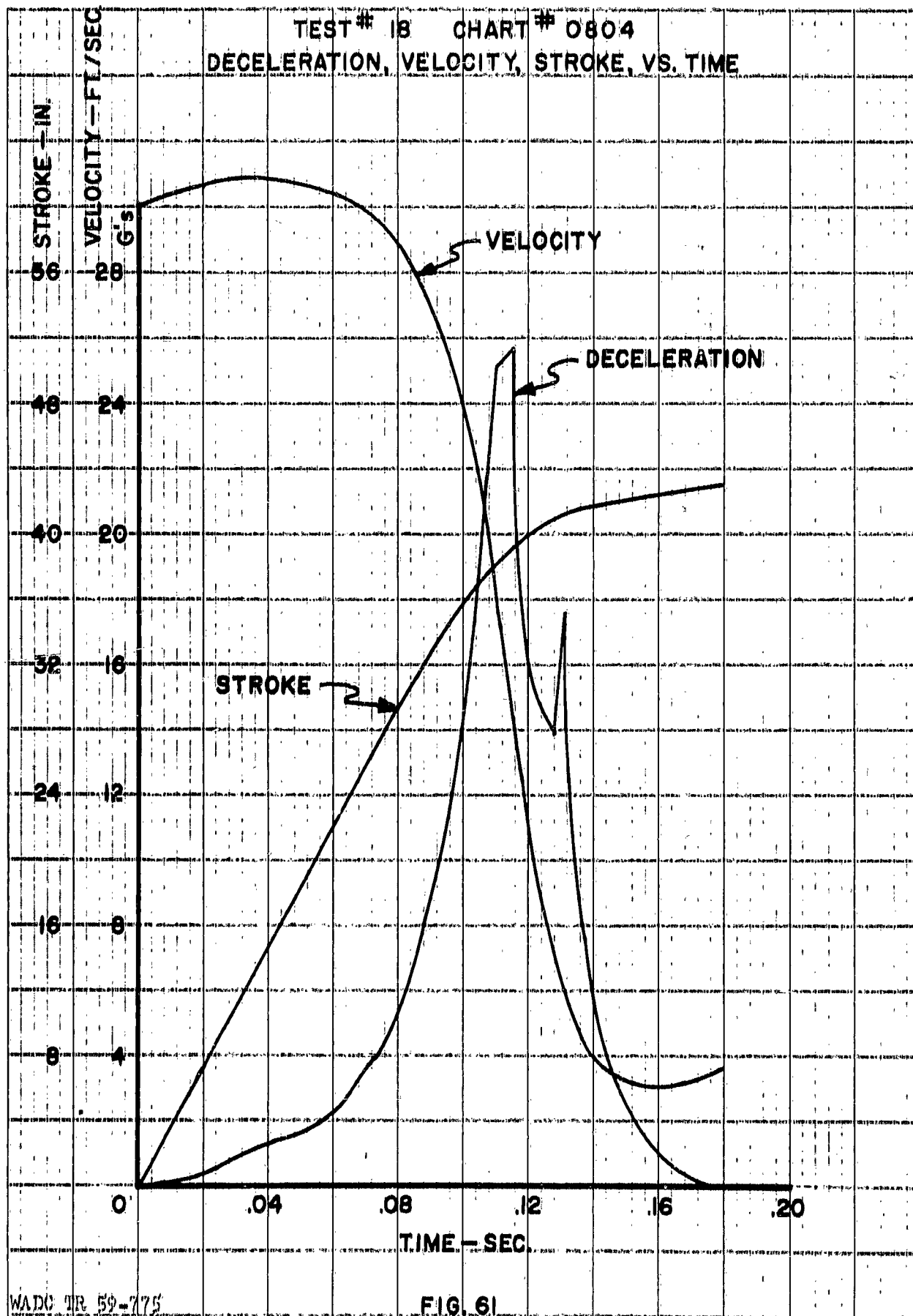
TEST #18   CHART #0804
G's VS STROKE
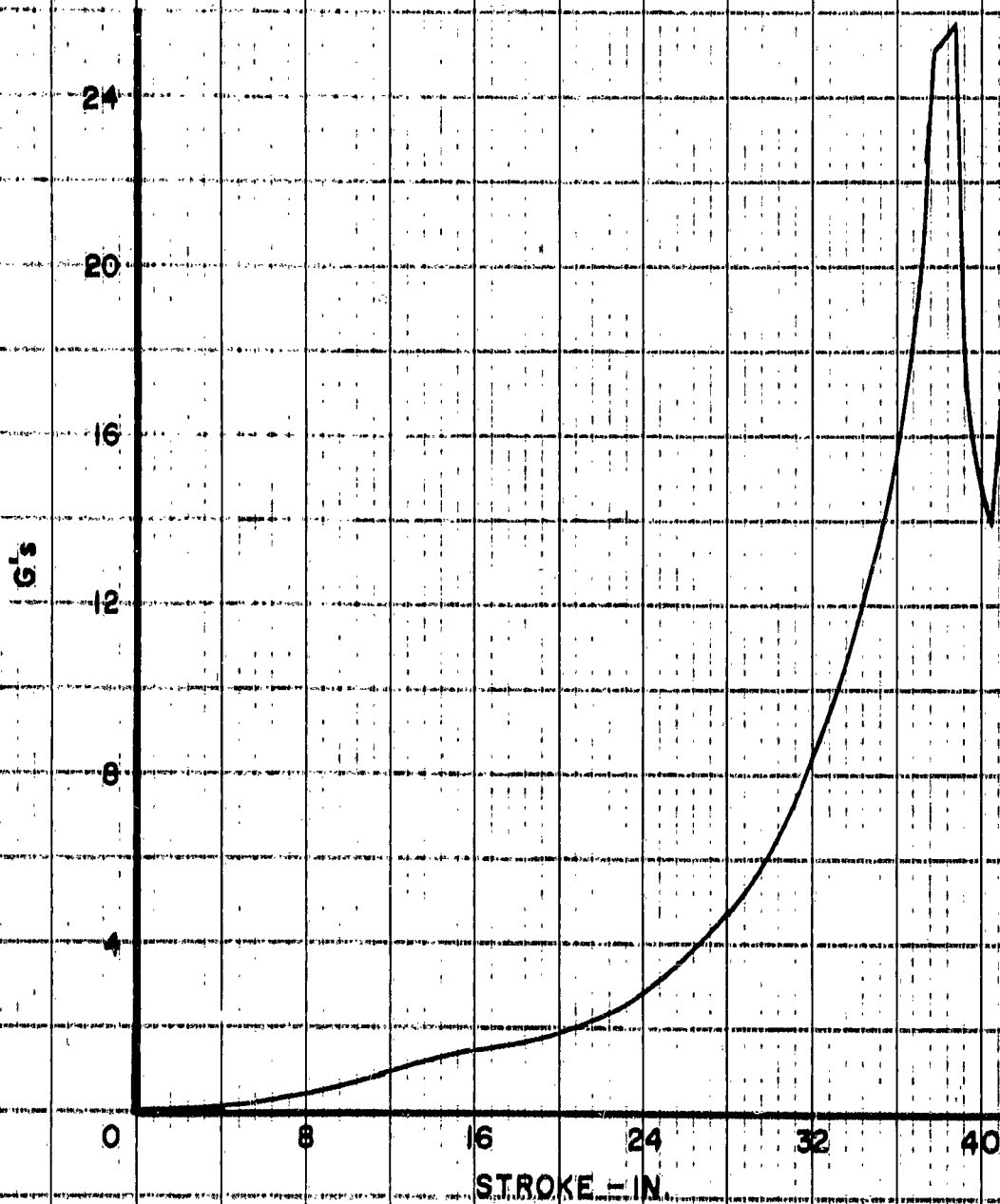
FIG. 62

WADC TR 59-775
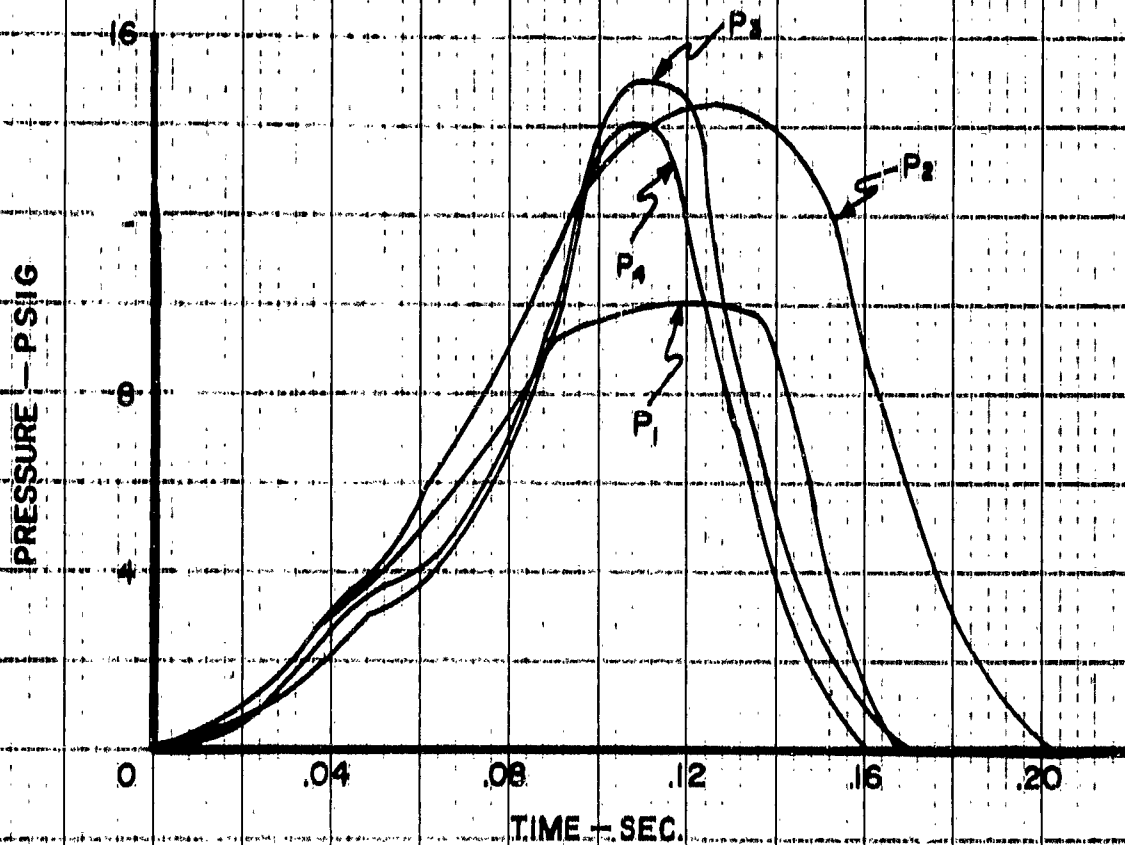
TEST # 18 CHART # 0804
WORK VS STROKE
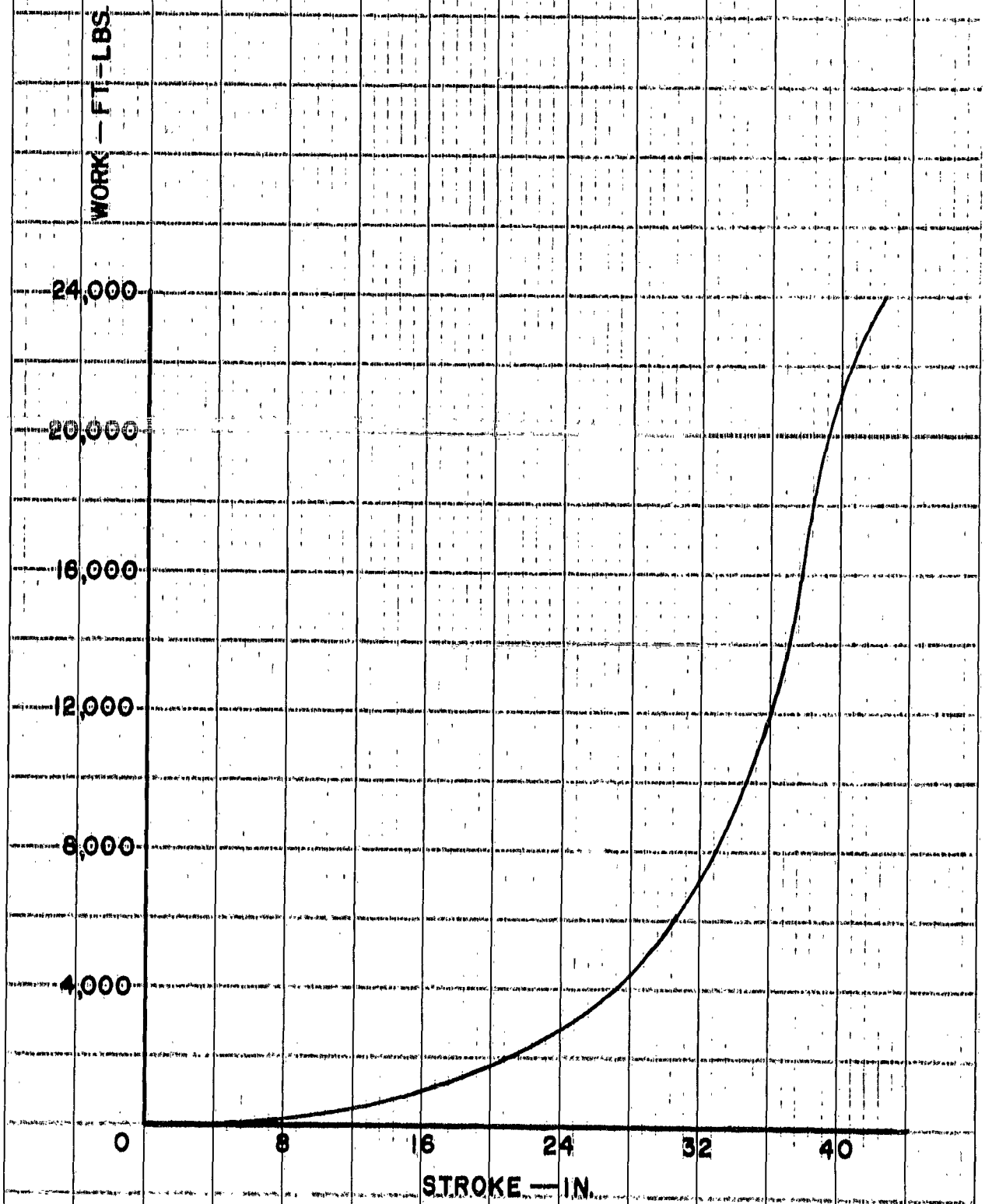
FIG. 63

WADO TR 52-776

TEST #19 CHART #0805
MULTIPLE (4) BAG DROP
35" DIA. X 40" LG. CYLINDRICAL BAGS
W=1350#/BAG D₀=4.5" Dₚ=6" V₀=29.62 FT./SEC.
PRESSURE VS. TIME
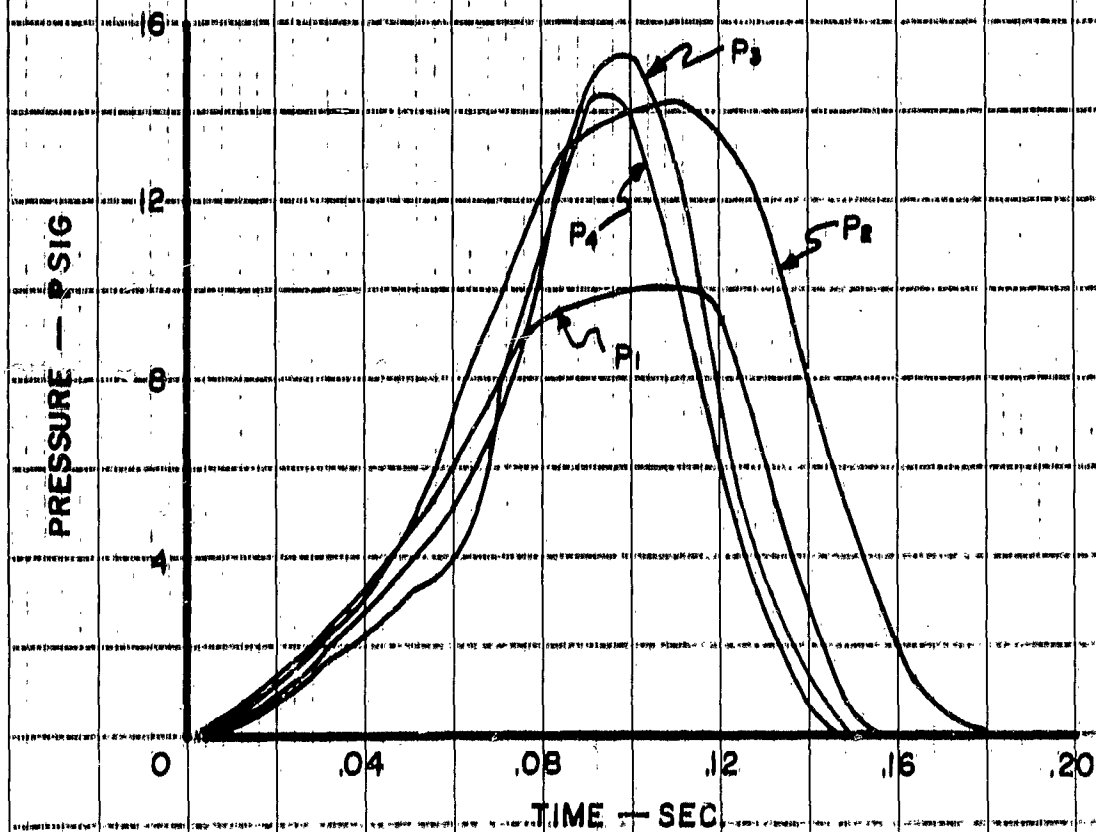
FIG. 64

WADC TR 59-775

TEST #19   CHART # 0805
DECELERATION, VELOCITY, STROKE VS. TIME
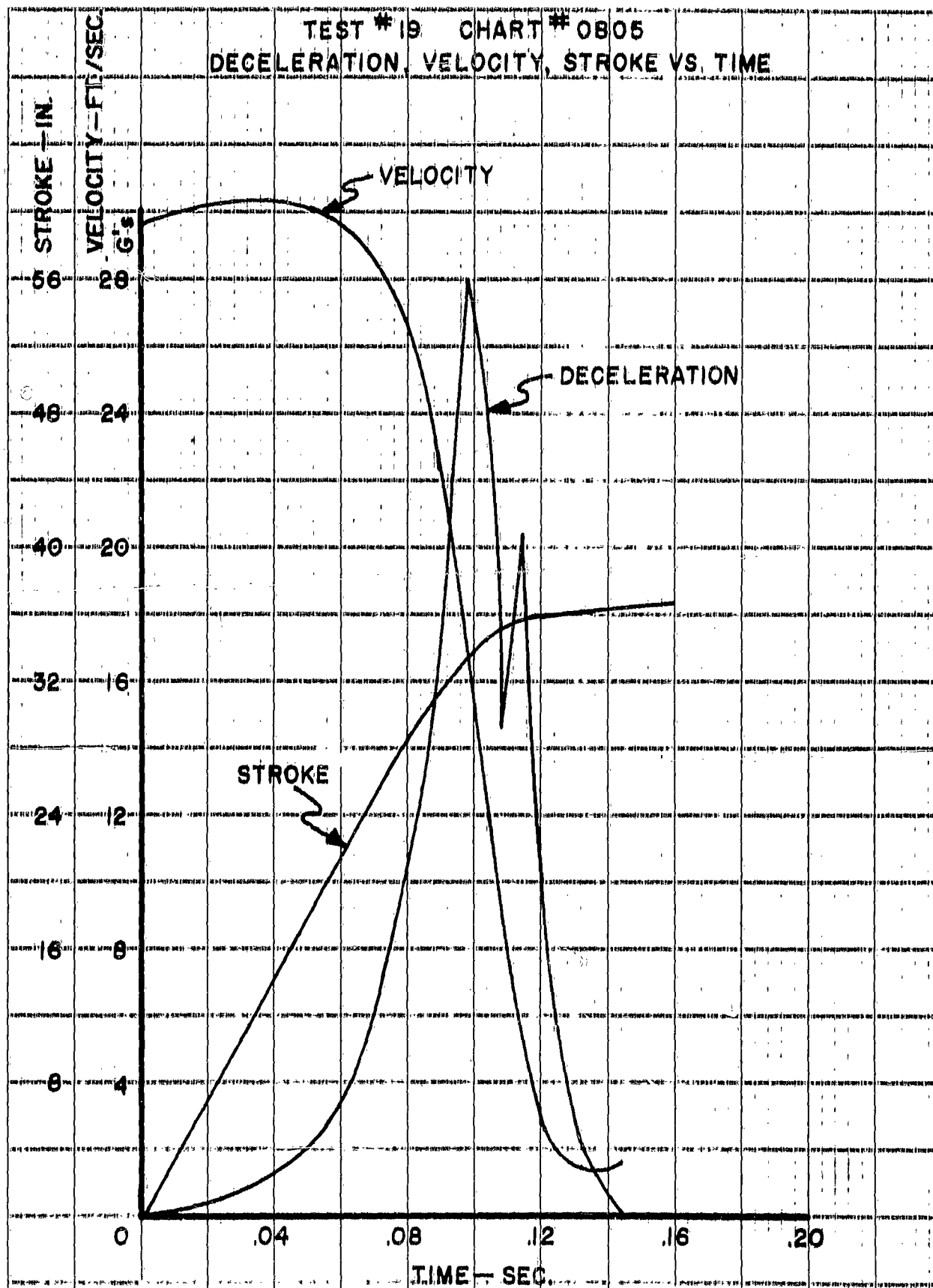
FIG. 65

WADC TR 59-175

TEST # 19   CHART # 0805
G's VS. STROKE

WADC TR 59-775   FIG. 66

96
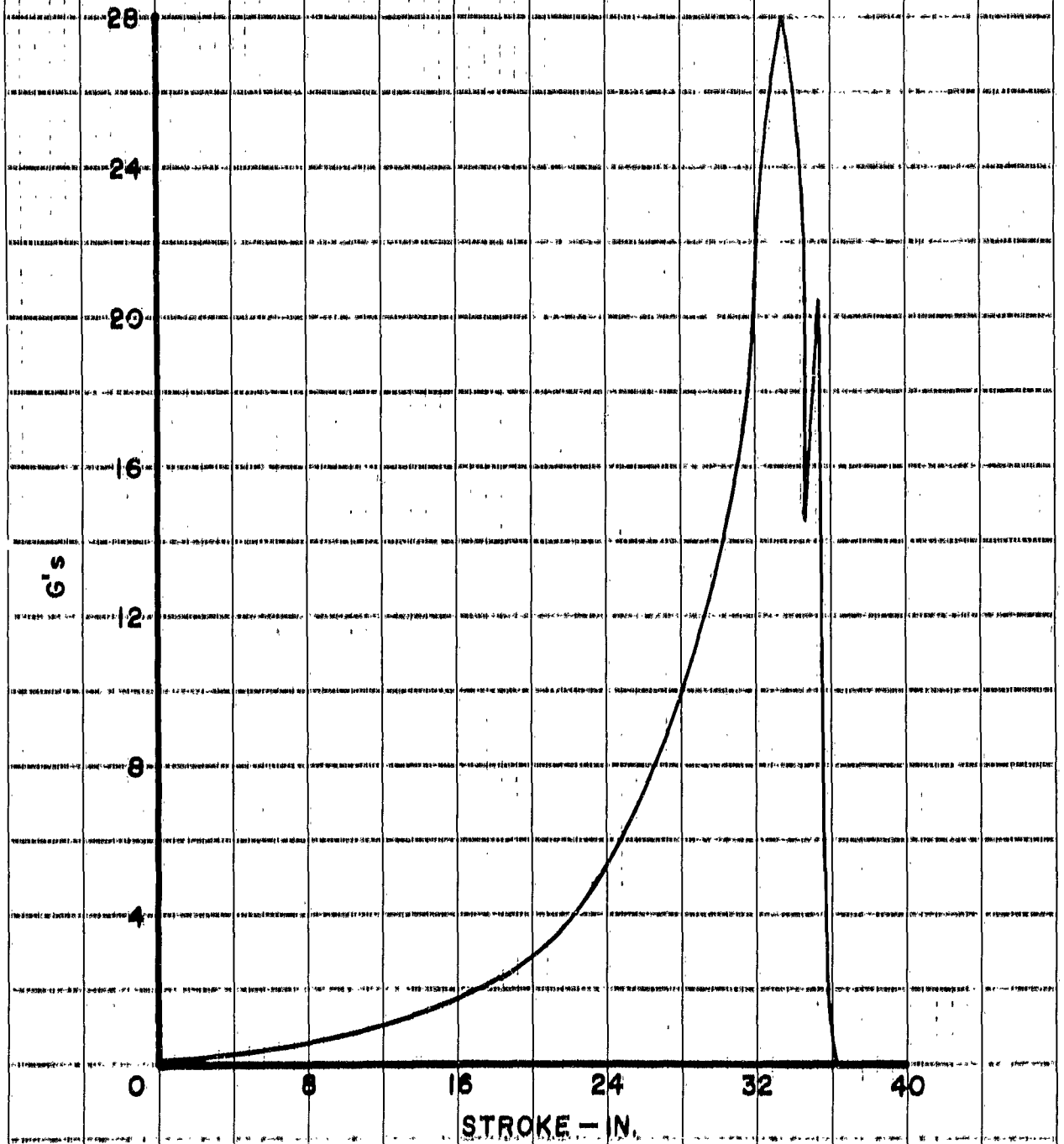
TEST #19 CHART # 0805
WORK VS. STROKE
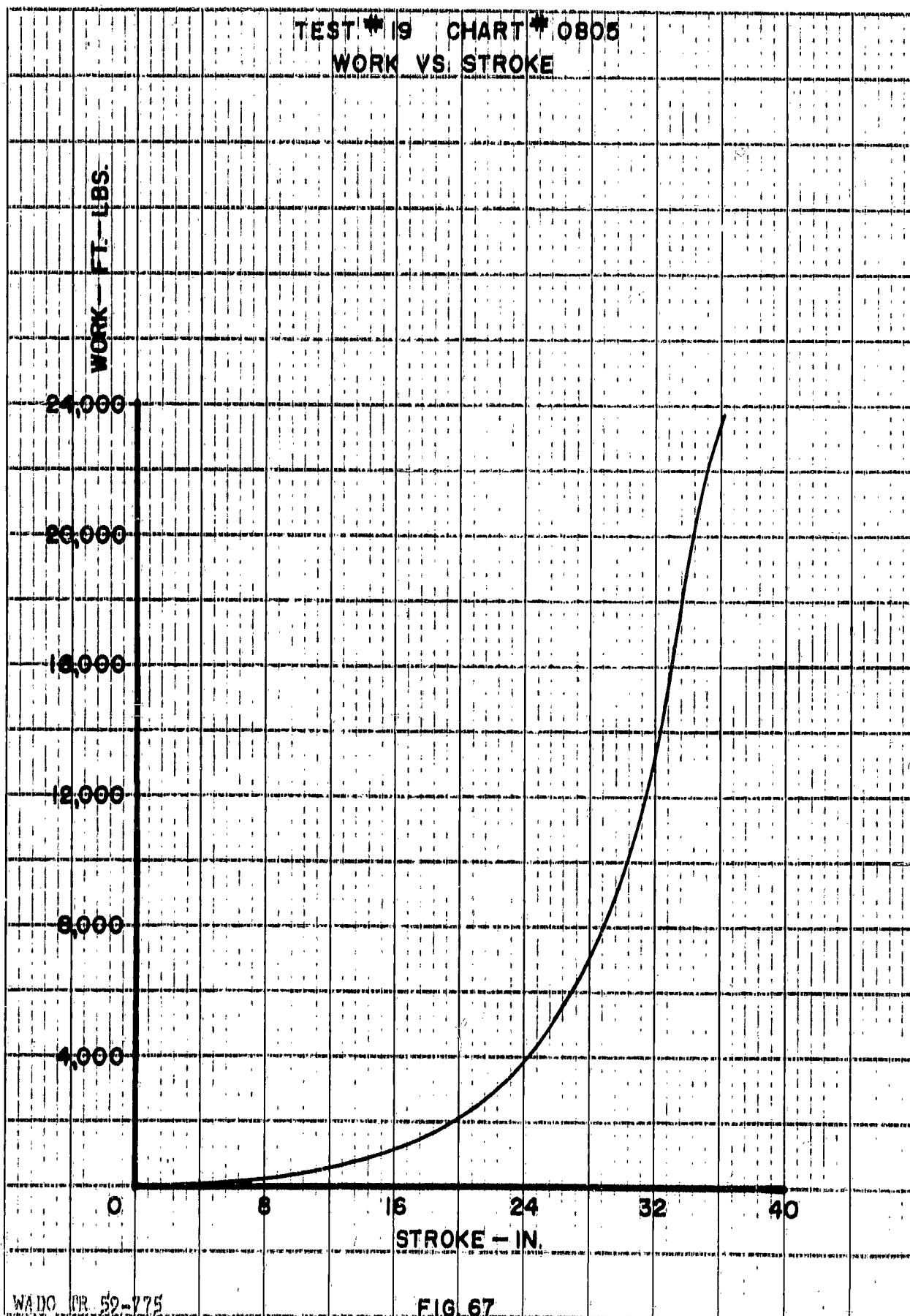
FIG. 67

WADC TR 52-775

97

TEST #20   CHART #0806
MULTIPLE (4) BAG DROP
35" DIA. X 35" LG. CYLINDRICAL BAGS
W=1350#/BAG D₀=4.5" Dₚ=6 V₀=29.56 FT./SEC.
PRESSURE VS. TIME

TEST #20 CHART #0806
DECELERATION, VELOCITY, STROKE VS TIME
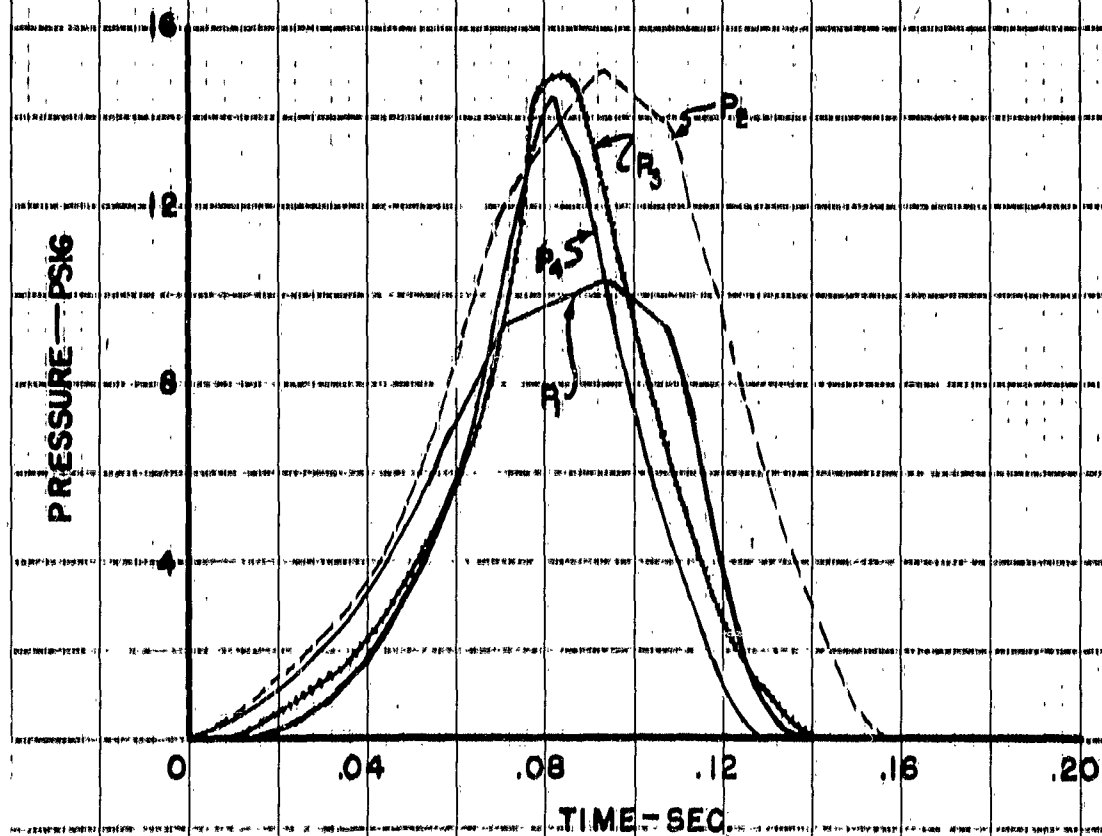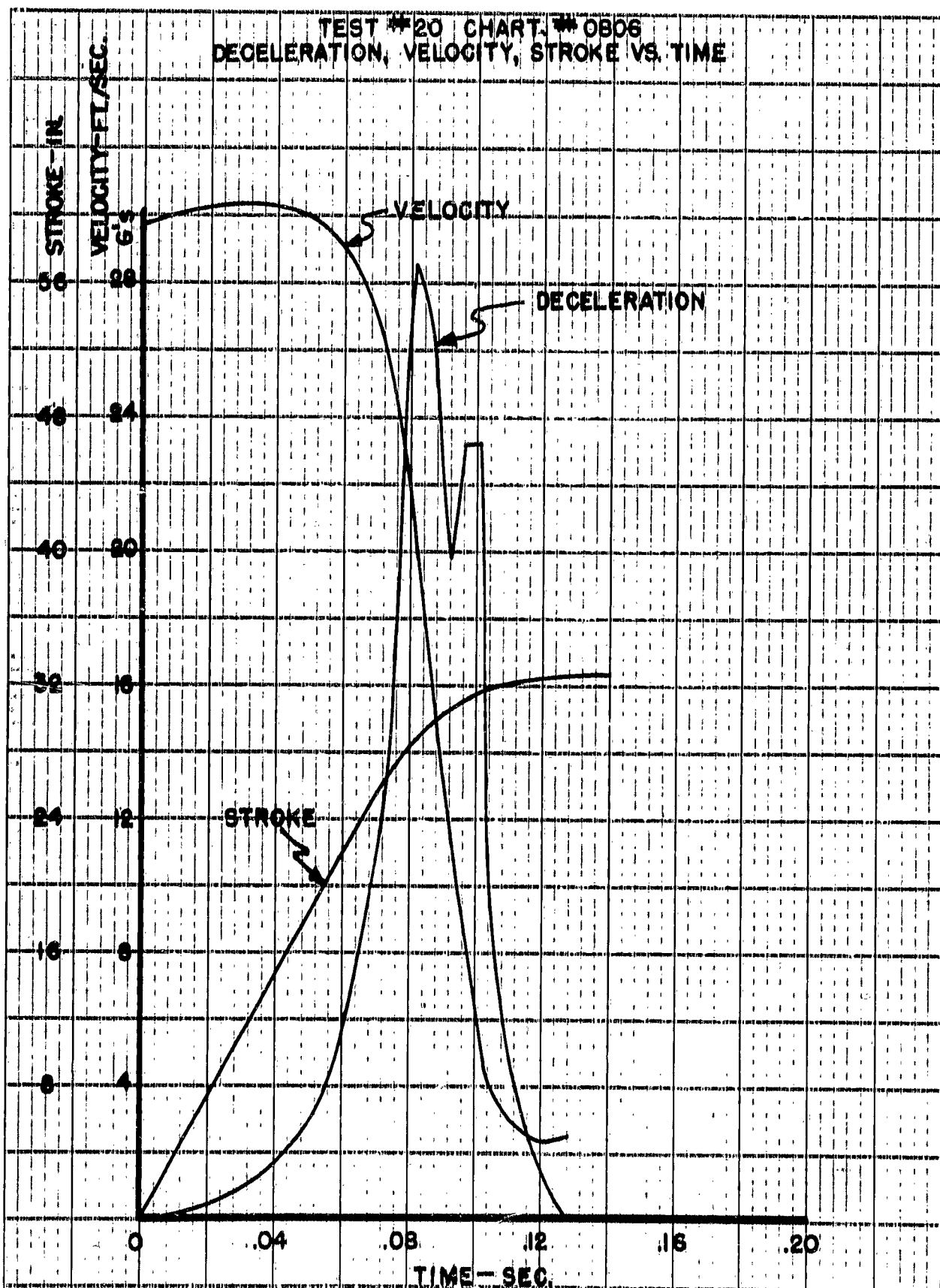
FIG. 69

TEST #20   CHART #0806
G'S VS. STROKE

FIG. 70

WADC TR 59-775
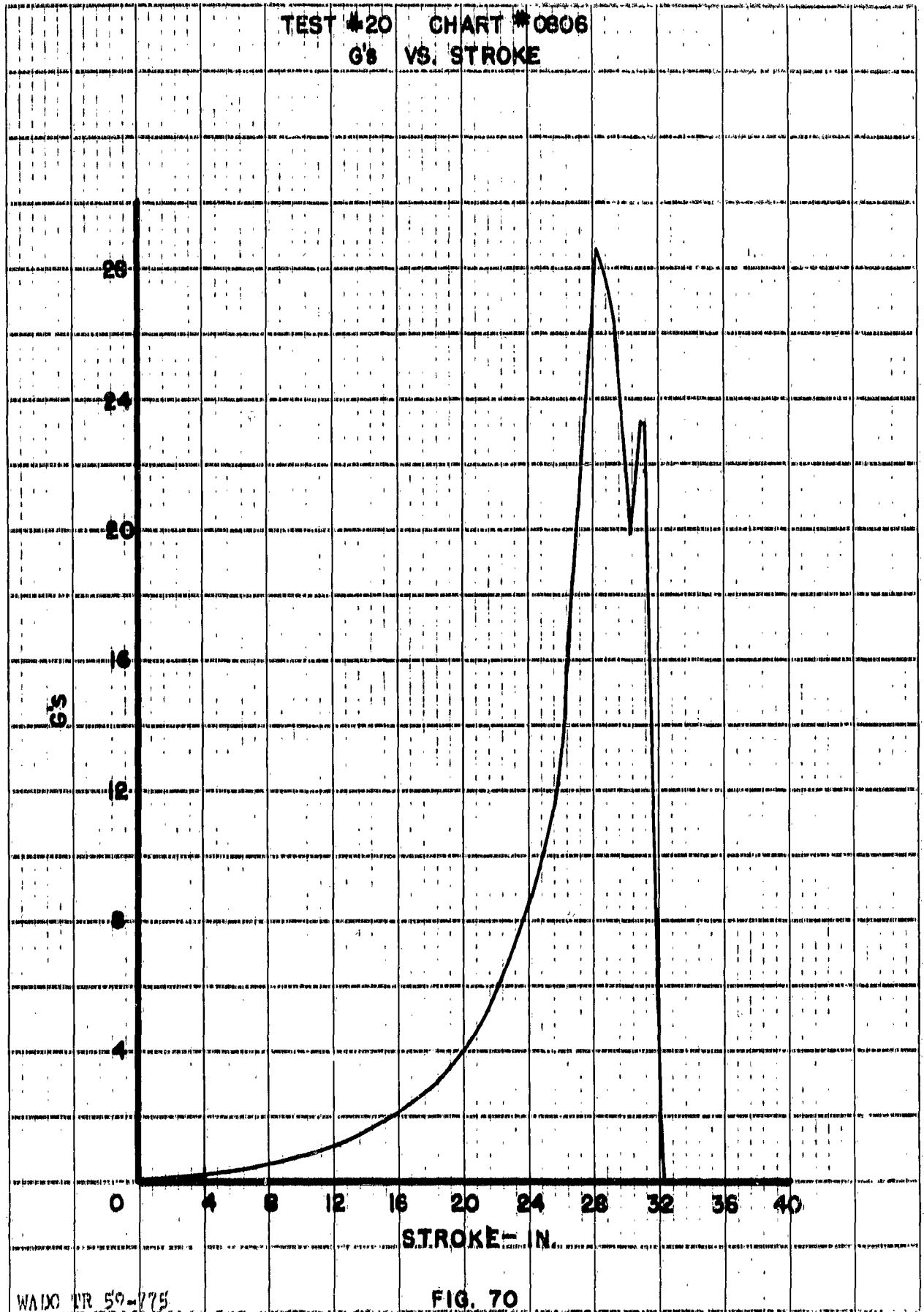
TEST #20   CHART #0806
WORK VS. STROKE
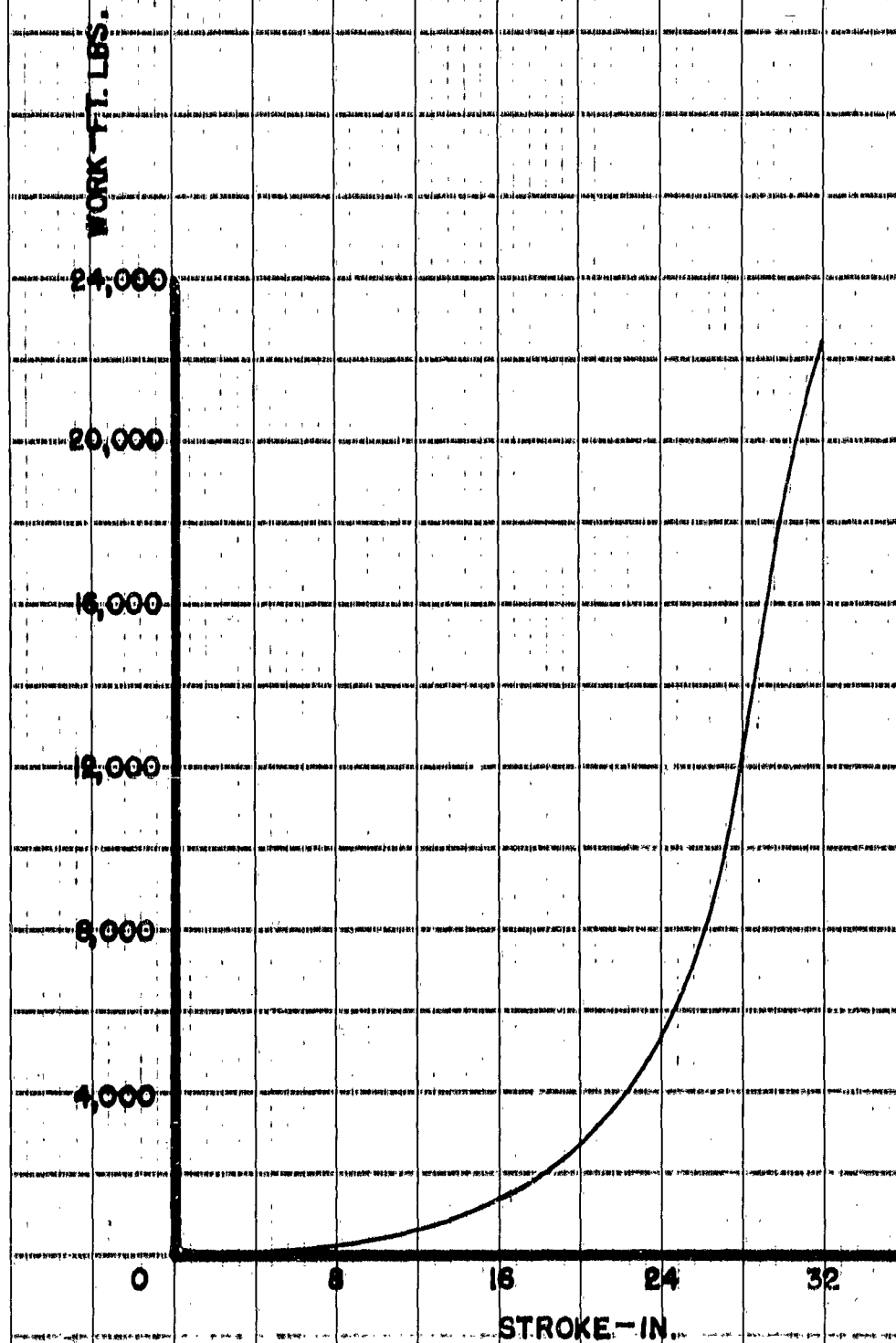
FIG. 71

TEST # 22   CHART # 0937
MULTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W = 1350 # / BAG   D = 5.25"   D = 6"   V = 29.30 FT. / SEC
PRESSURE VS. TIME

PRESSURE — PSIG

16
12
8
4

P_4
P_1
P_3

0   .04   .08   .12   .16   .20   .22

TIME — SEC.

TEST # 22   CHART # 0837
DECELERATION, VELOCITY, STROKE, VS. TIME

VELOCITY

STROKE

DECELERATION

TIME — SEC.
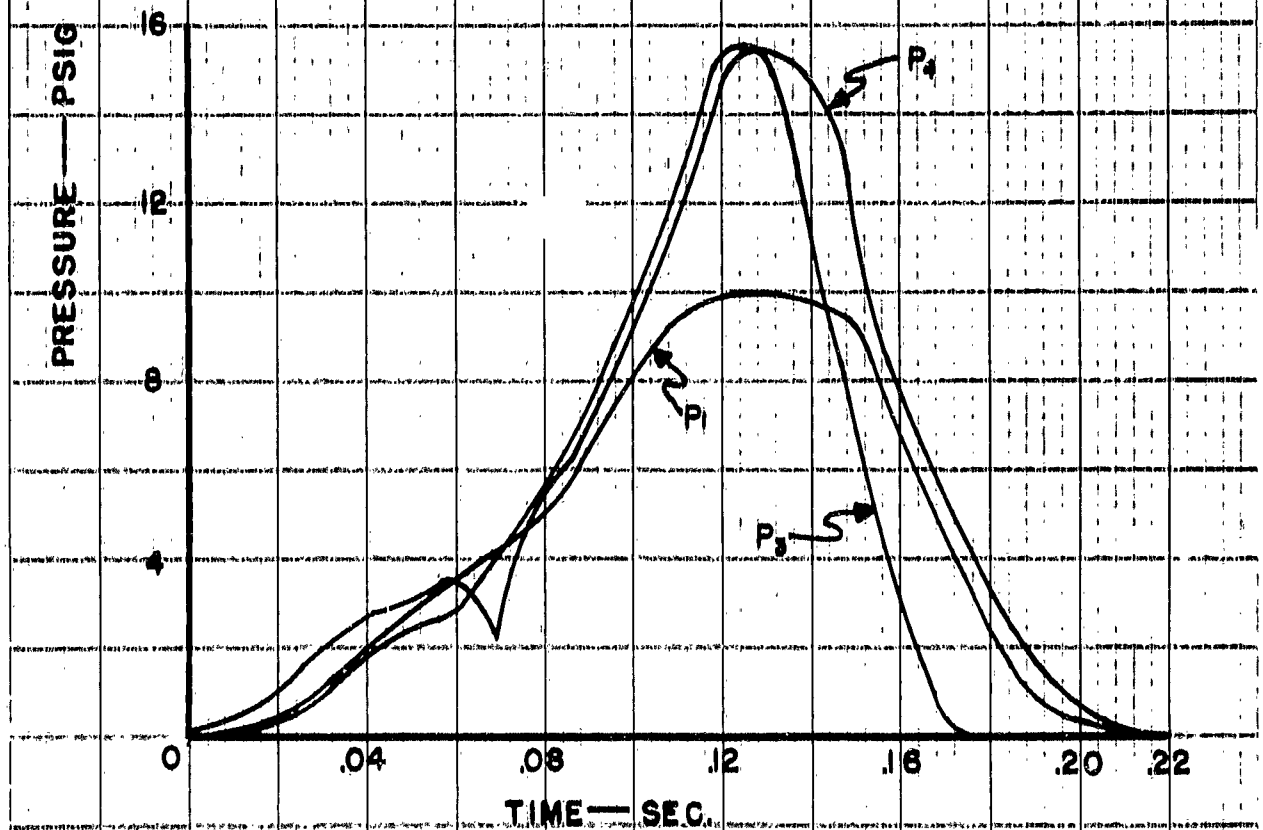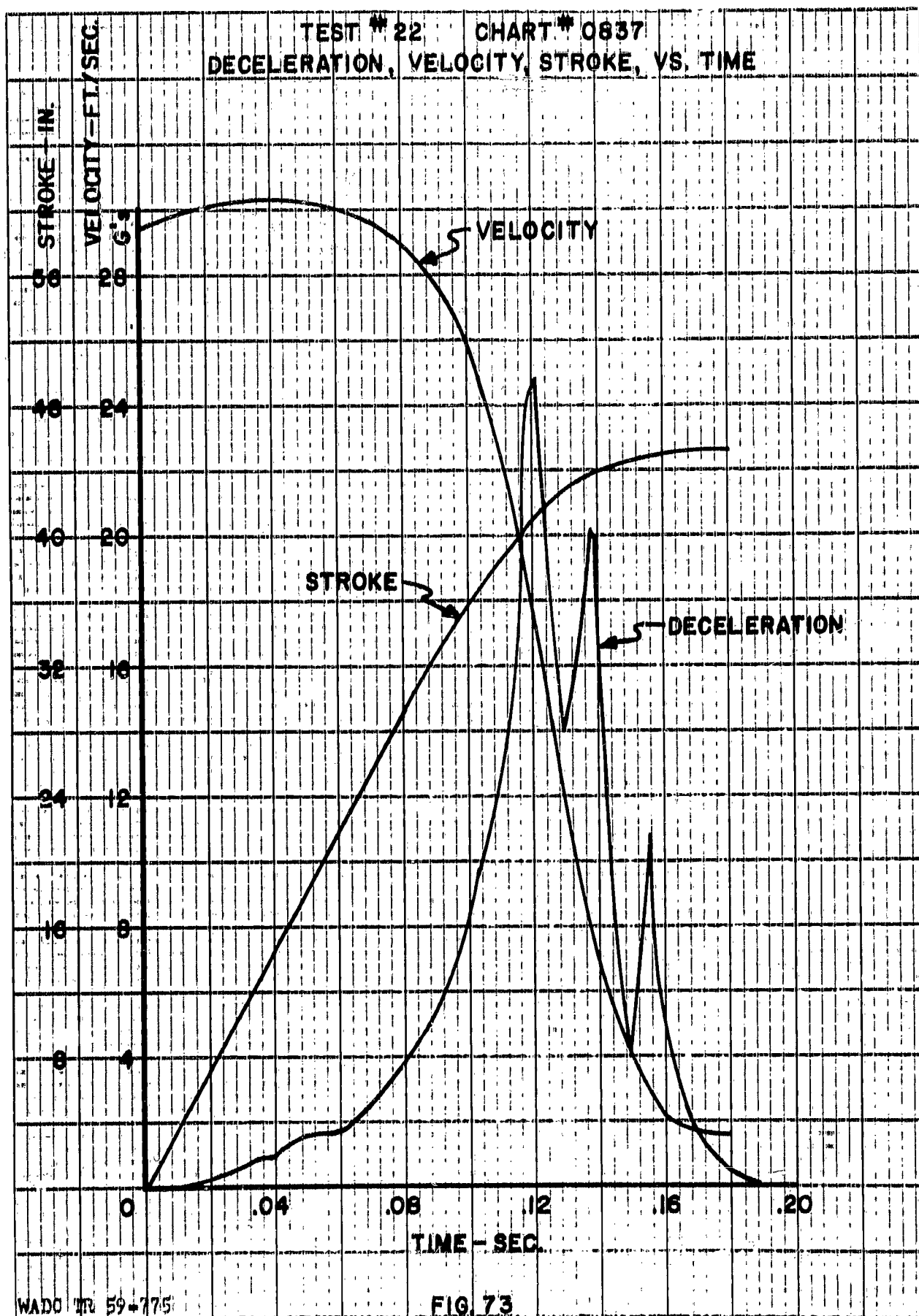
WADC TR 59-775   FIG. 73

103

TEST #22   CHART #0837
G's VS. STROKE
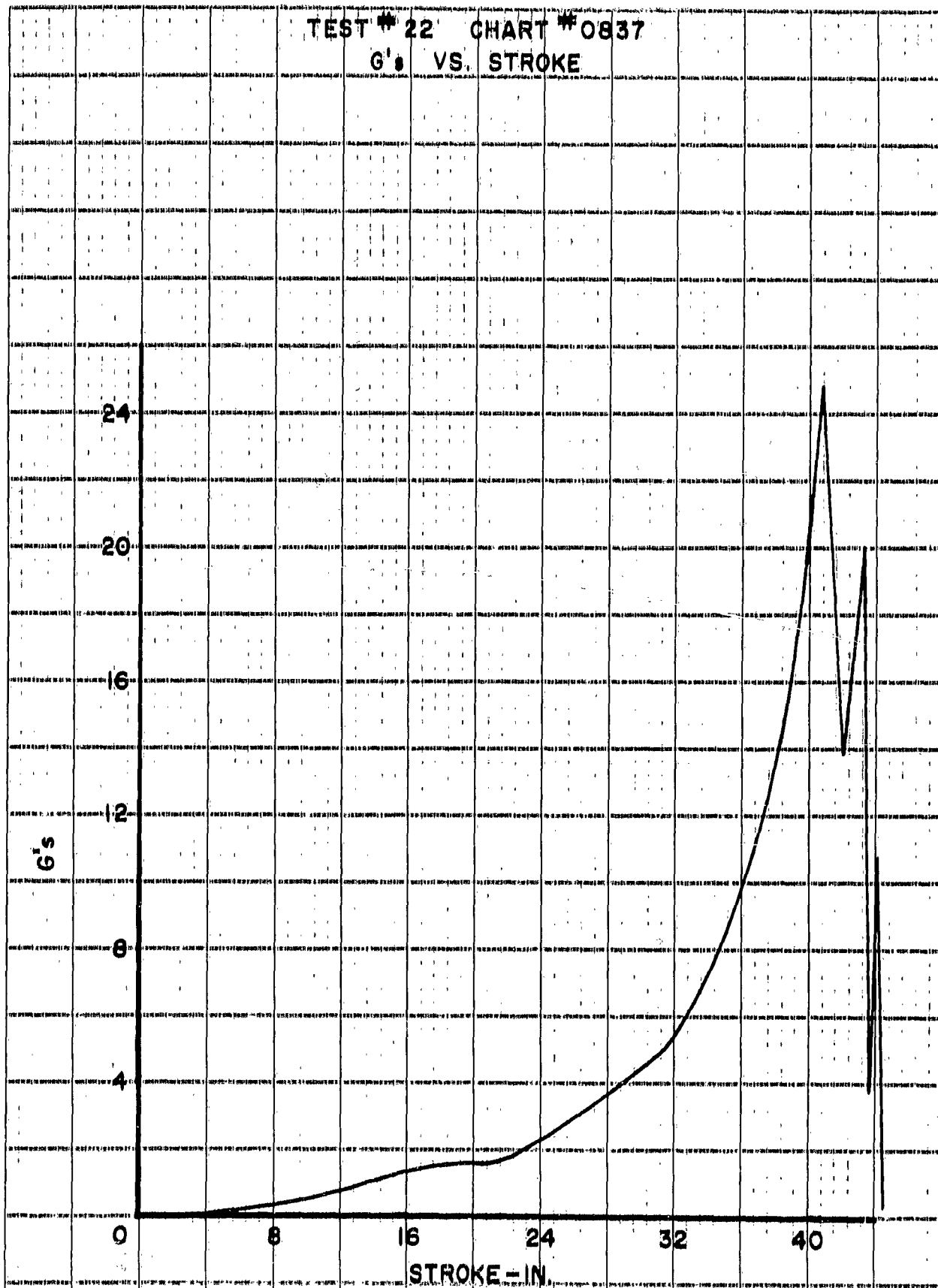
WADC TR 59-775

FIG. 74

104

TEST #22   CHART #0837
WORK VS. STROKE
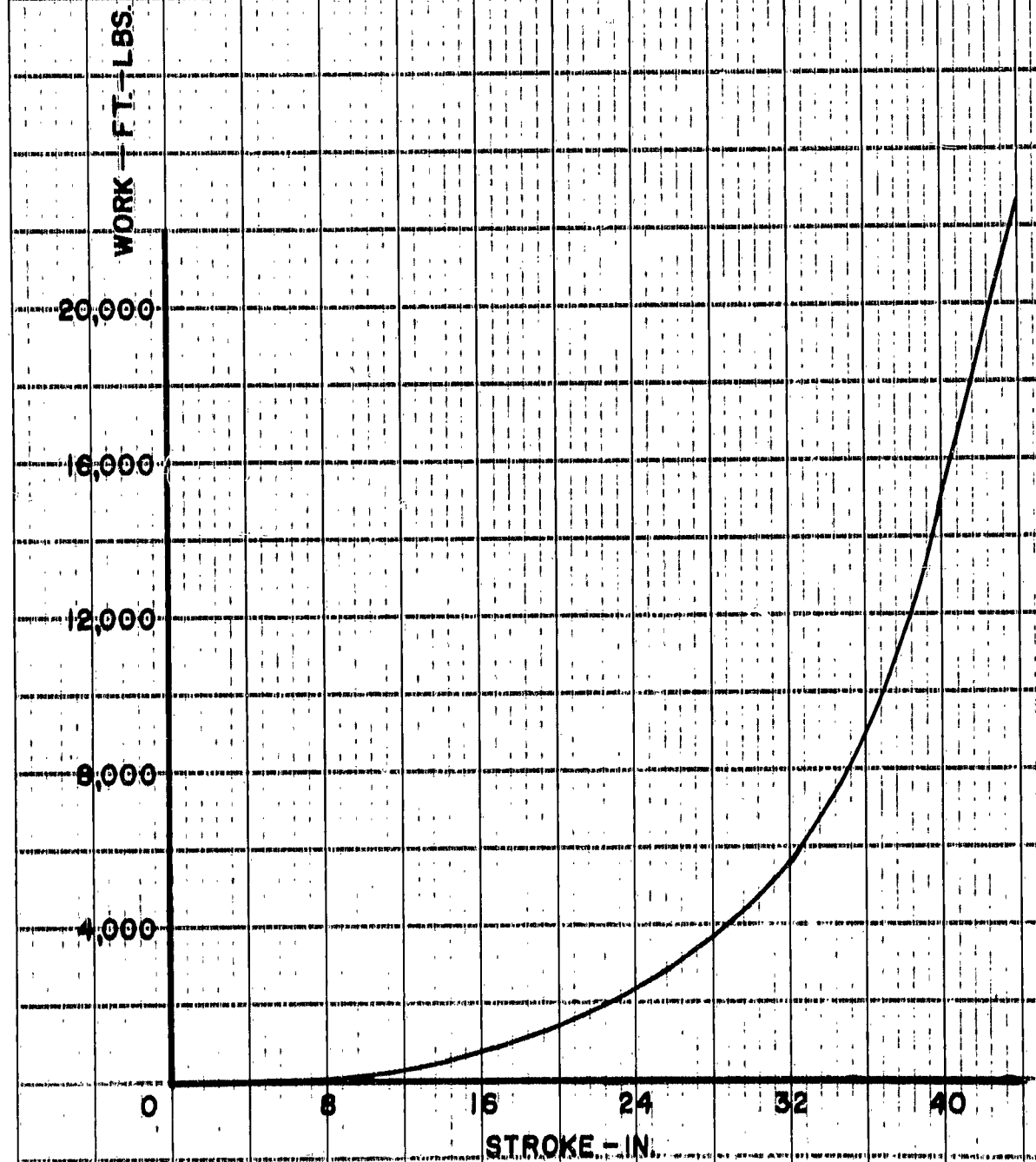
FIG. 75

TEST # 23   CHART # 0856
MUTIPLE (4) BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAGS
W = 1350 # / BAG D = 5.0' D = 6.5" V = 29.79 FT./SEC.
PRESSURE VS TIME
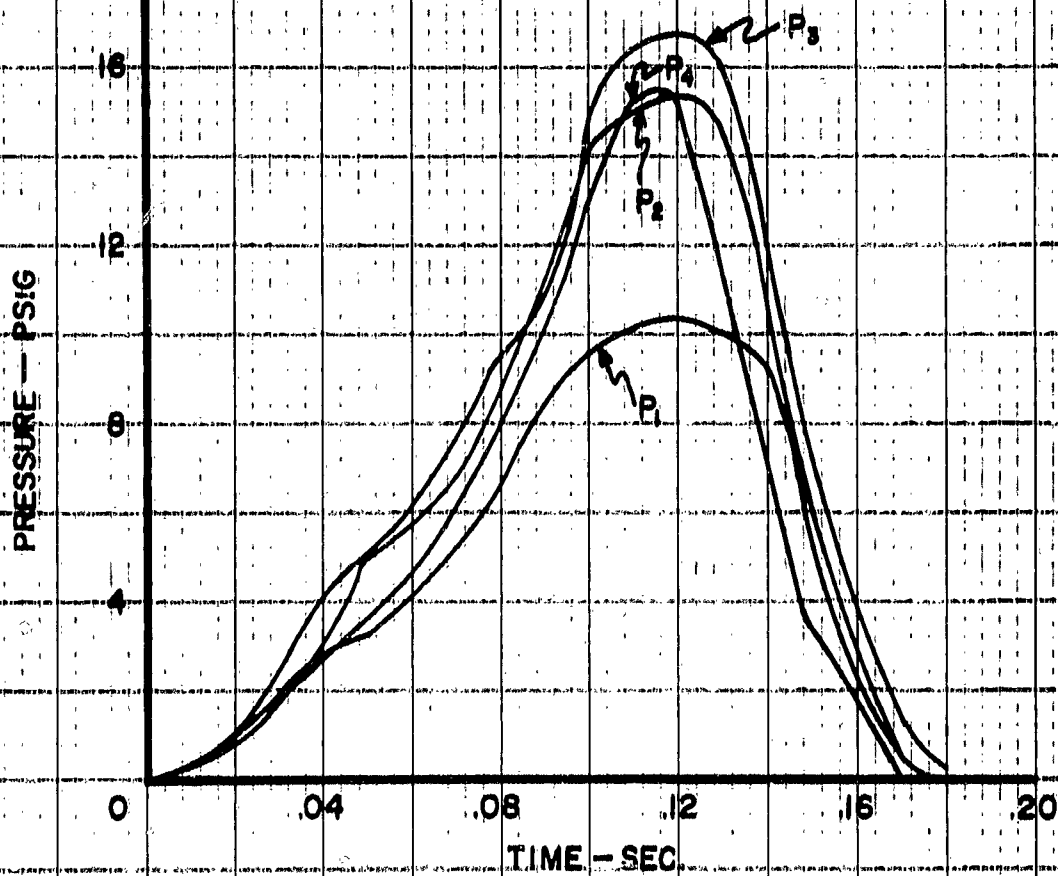
WADC TR 59-775

FIG. 76

TEST # 23   CHART # 0856
DECELERATION, VELOCITY, STROKE VS. TIME

VELOCITY

DECELERATION

STROKE

TIME — SEC.
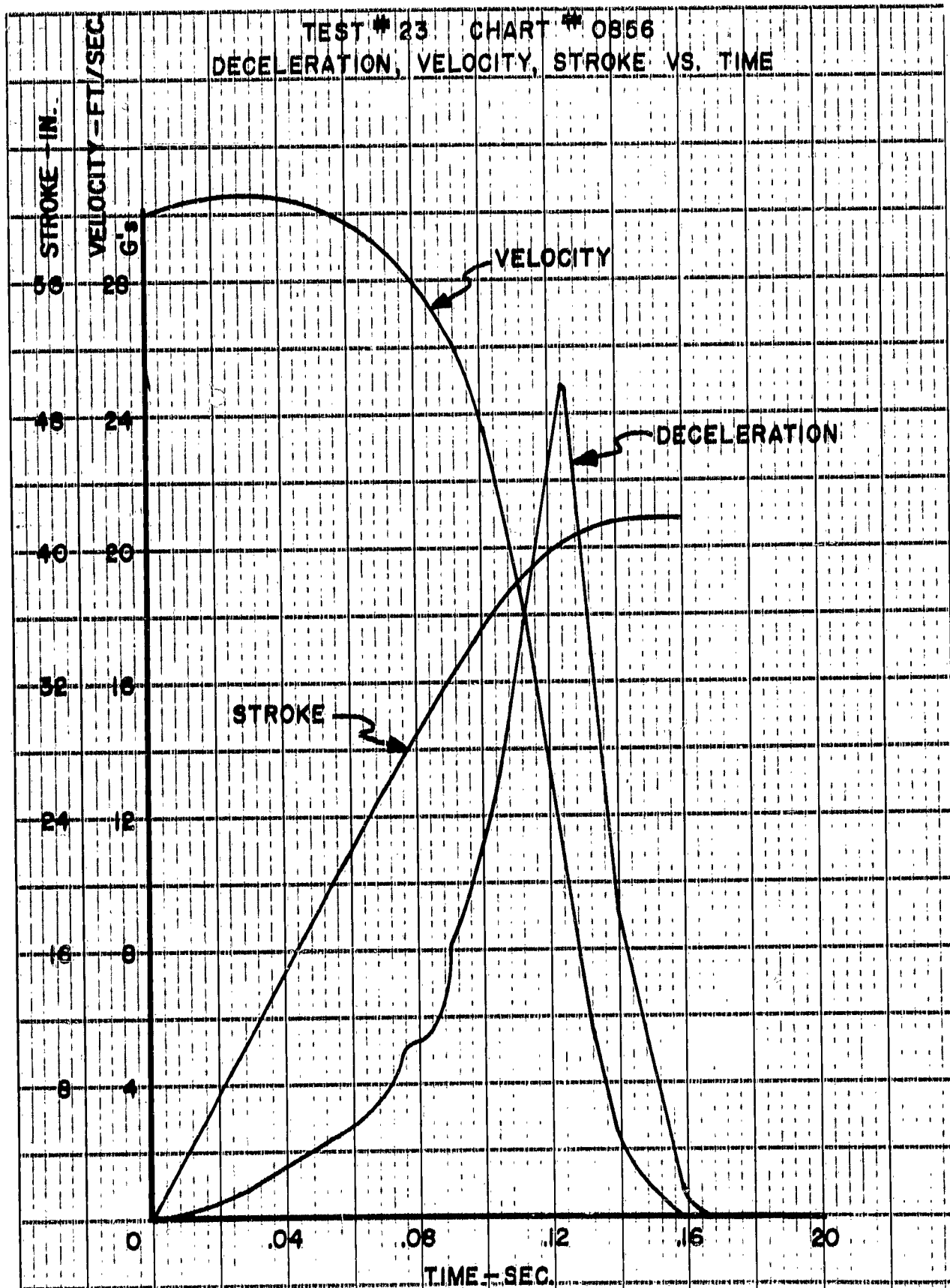
WADC TR 59-775

FIG. 7.7

107

TEST # 23   CHART # 0856
G's   VS STROKE

G's
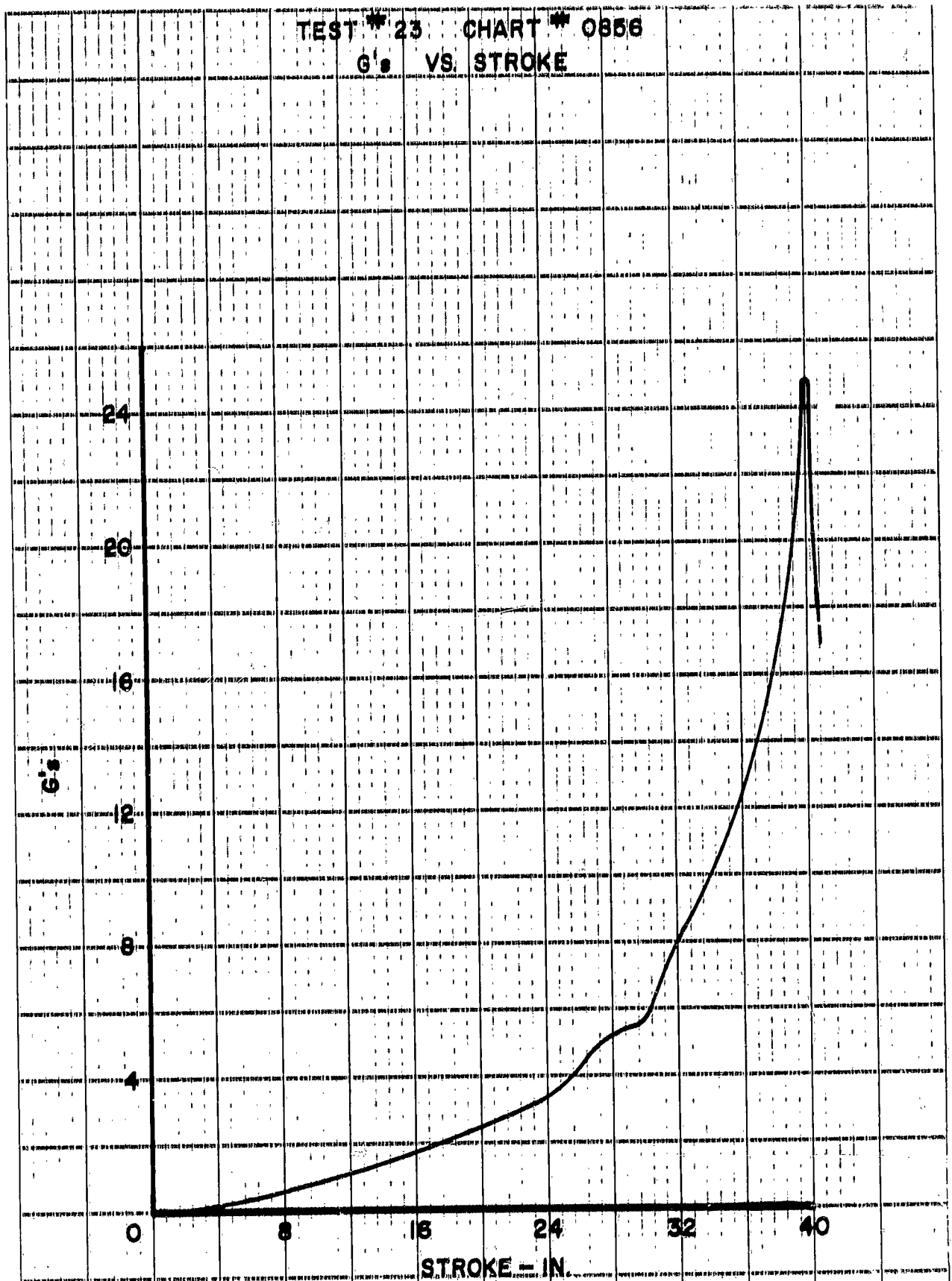
STROKE — IN.

TEST #23   CHART # 0856
WORK VS. STROKE
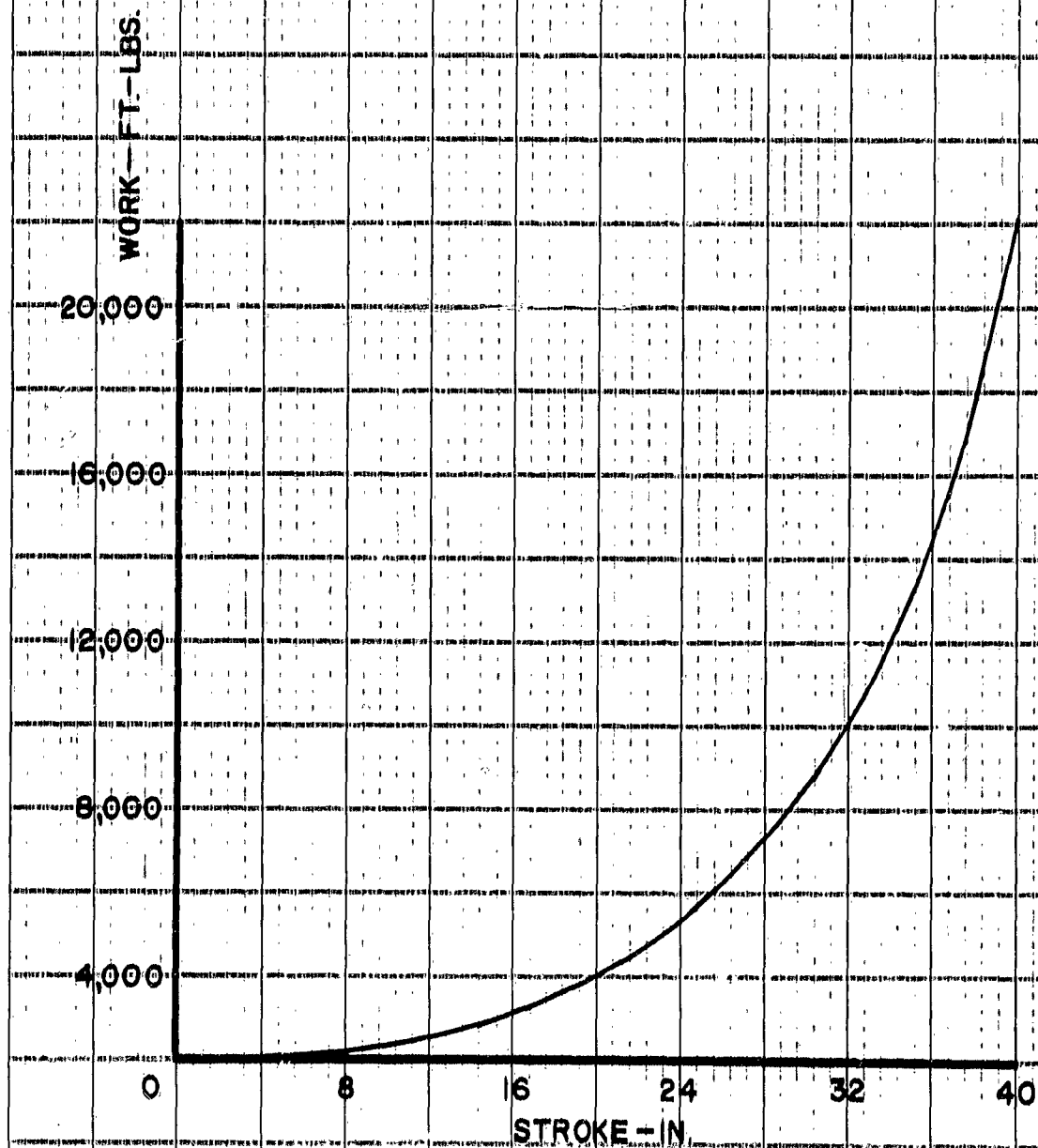
FIG. 79

TEST # 25   CHART # 0963
SINGLE BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAG
W=1385# D=5" D=6.5" V=26.9 FT/SEC.
PRESSURE VS. TIME

PRESSURE – PSIG

TIME – SEC

TEST # 25   CHART # 0963
DECELERATION, VELOCITY, — — — STROKE VS. TIME

VELOCITY

DECELERATION

STROKE

TIME – SEC.

WADC TR 59-Y25

FIG. 81

III
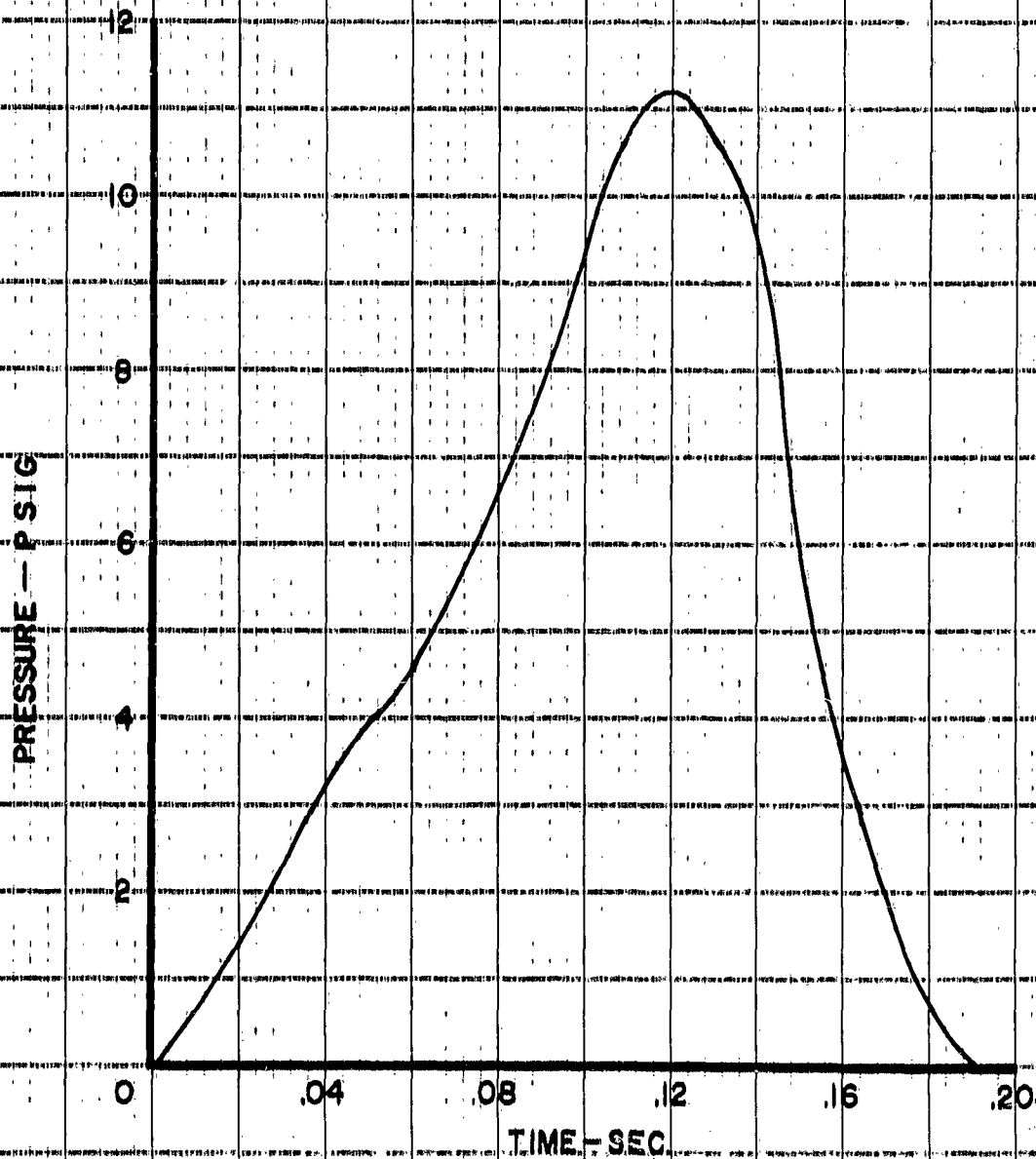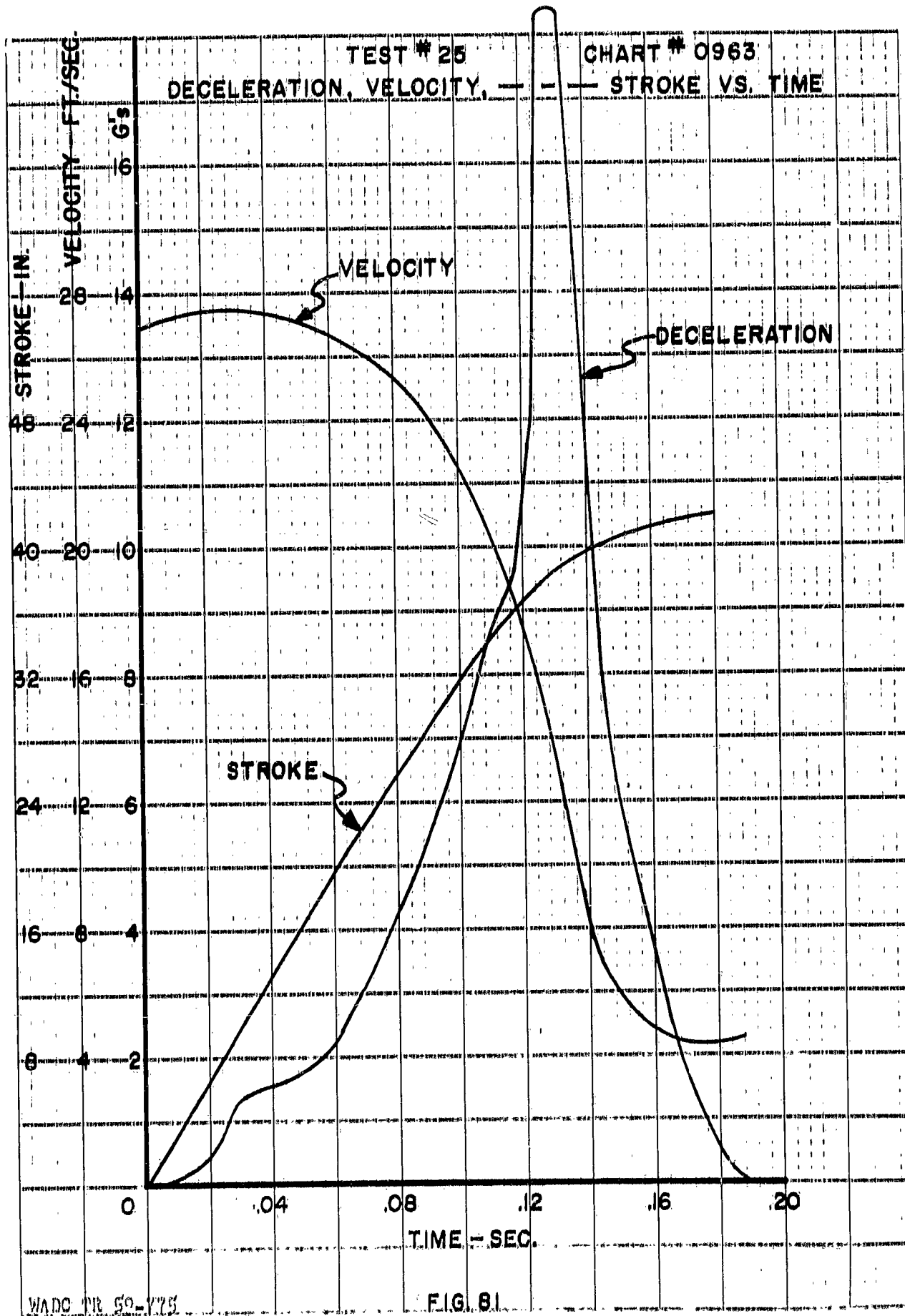
TEST #25   CHART #0963
G's VS. STROKE
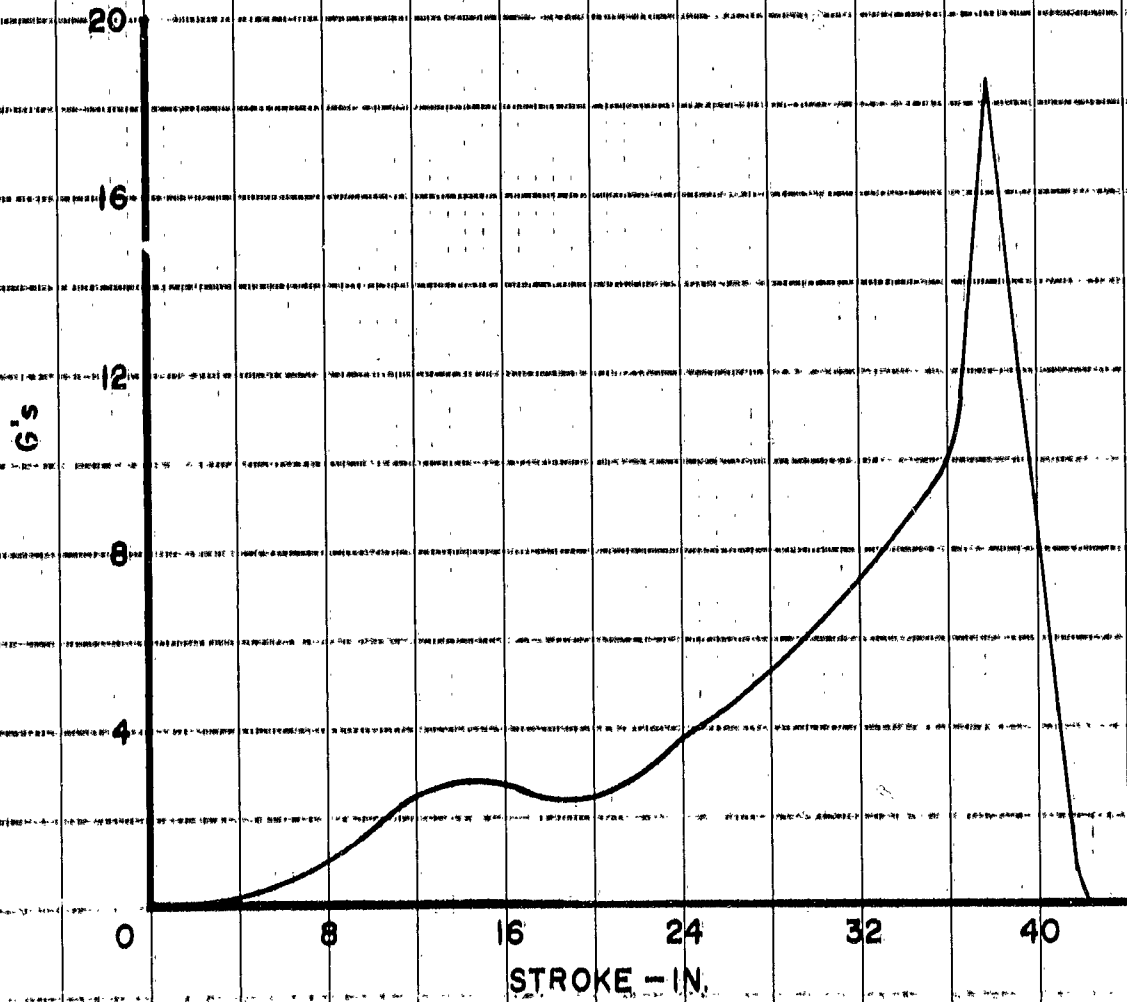
FIG. 82

TEST # 25 CHART # 0963
WORK VS. STROKE
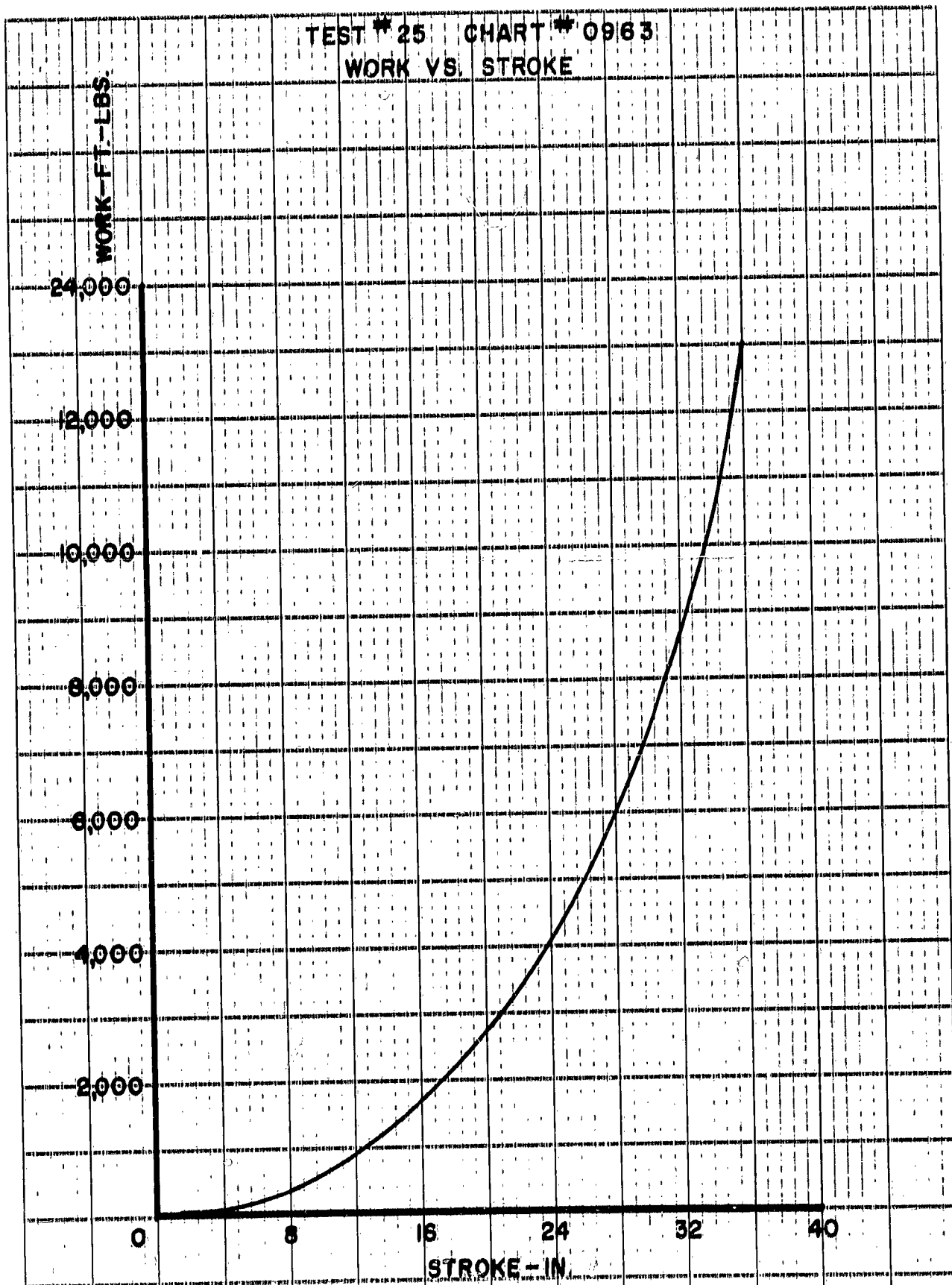
FIG. 83

WADC TR 59-775

113

TEST – 30   CHART – 0990
SINGLE BAG DROP
35" DIA. X 45" LG. CYLINDRICAL BAG
W=1385#/BAG D₀=5.5" Dₚ=6.5" V₀=26.7 FT./SEC.
PRESSURE vs. TIME

FIG. 64

TEST —30 CHART —0990
DECELERATION, VELOCITY, STROKE vs. TIME

VELOCITY

STROKE

DECELERATION

TIME — SEC.

WADC TR 59-775

FIG. 85

115
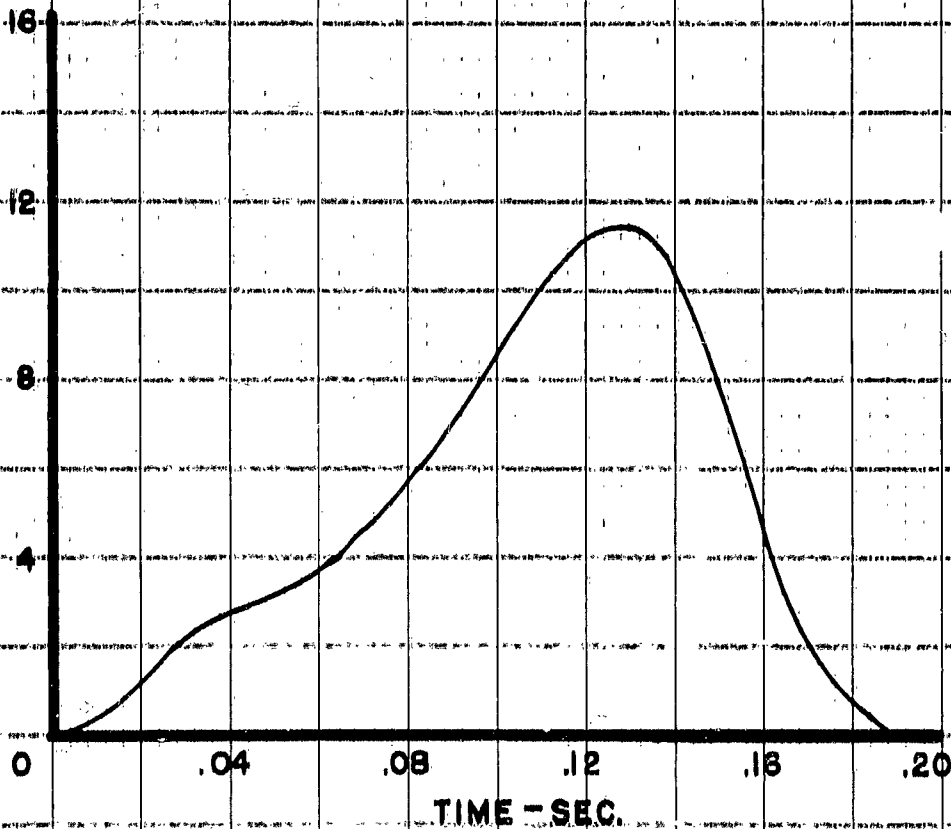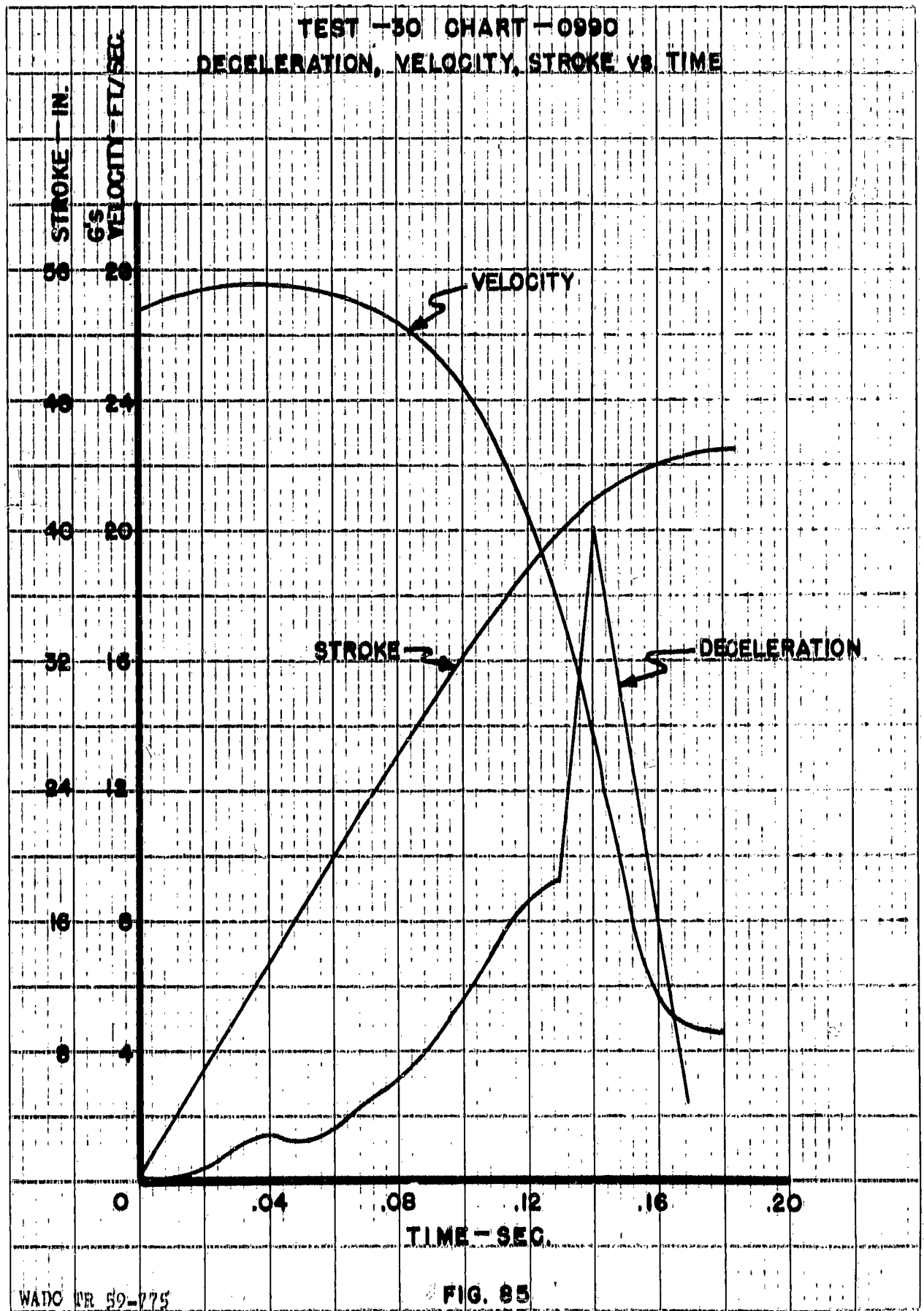
TEST #30   CHART #0890
Gs VS STROKE
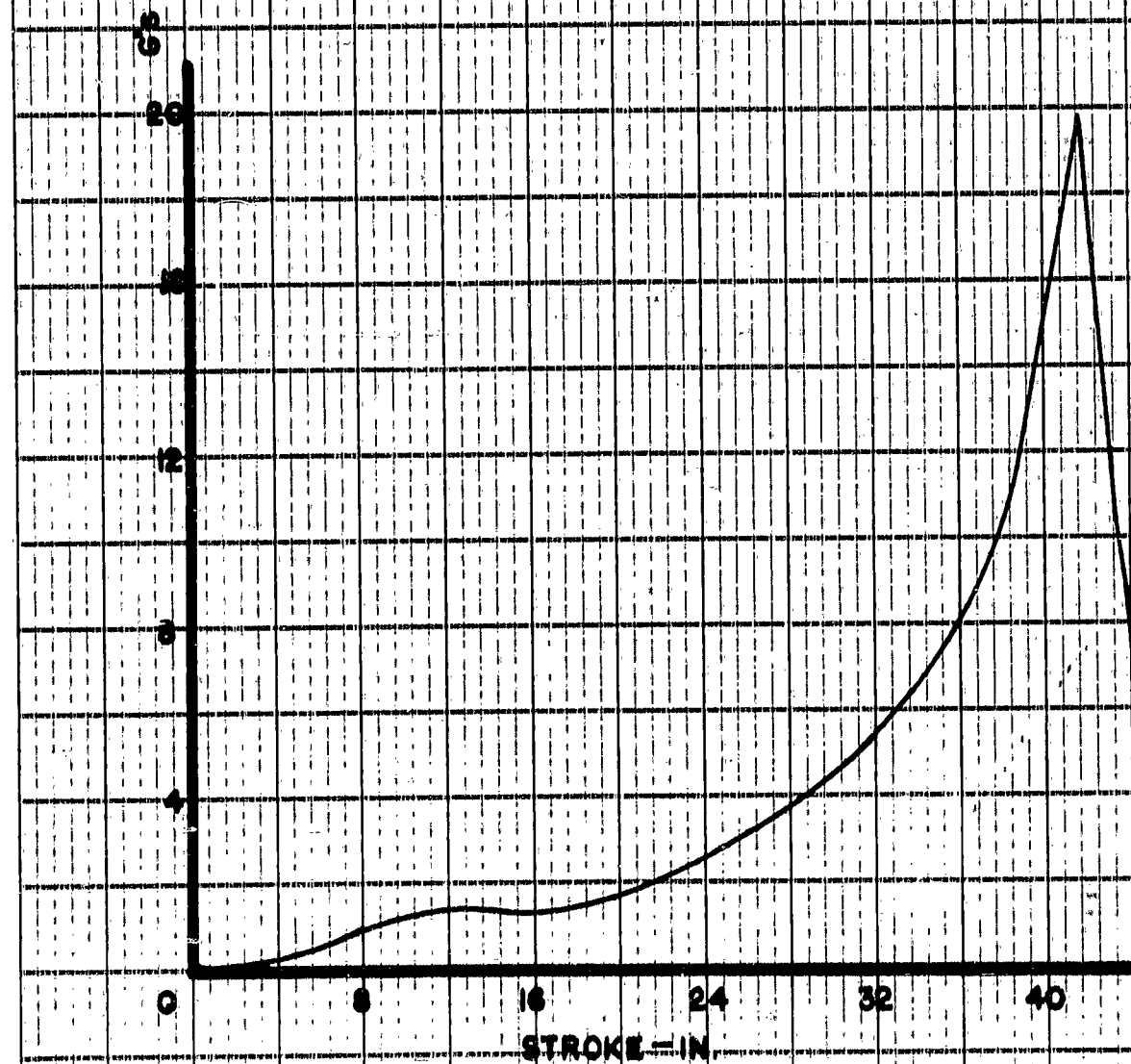
FIG. 86

WADC TR 59-775

TEST #30 CHART #0990
WORK VS. STROKE

WORK—FT. LBS.

STROKE—IN.

14,000

12,000

10,000

8,000

6,000

4,000

2,000

0   8   16   24   32   40
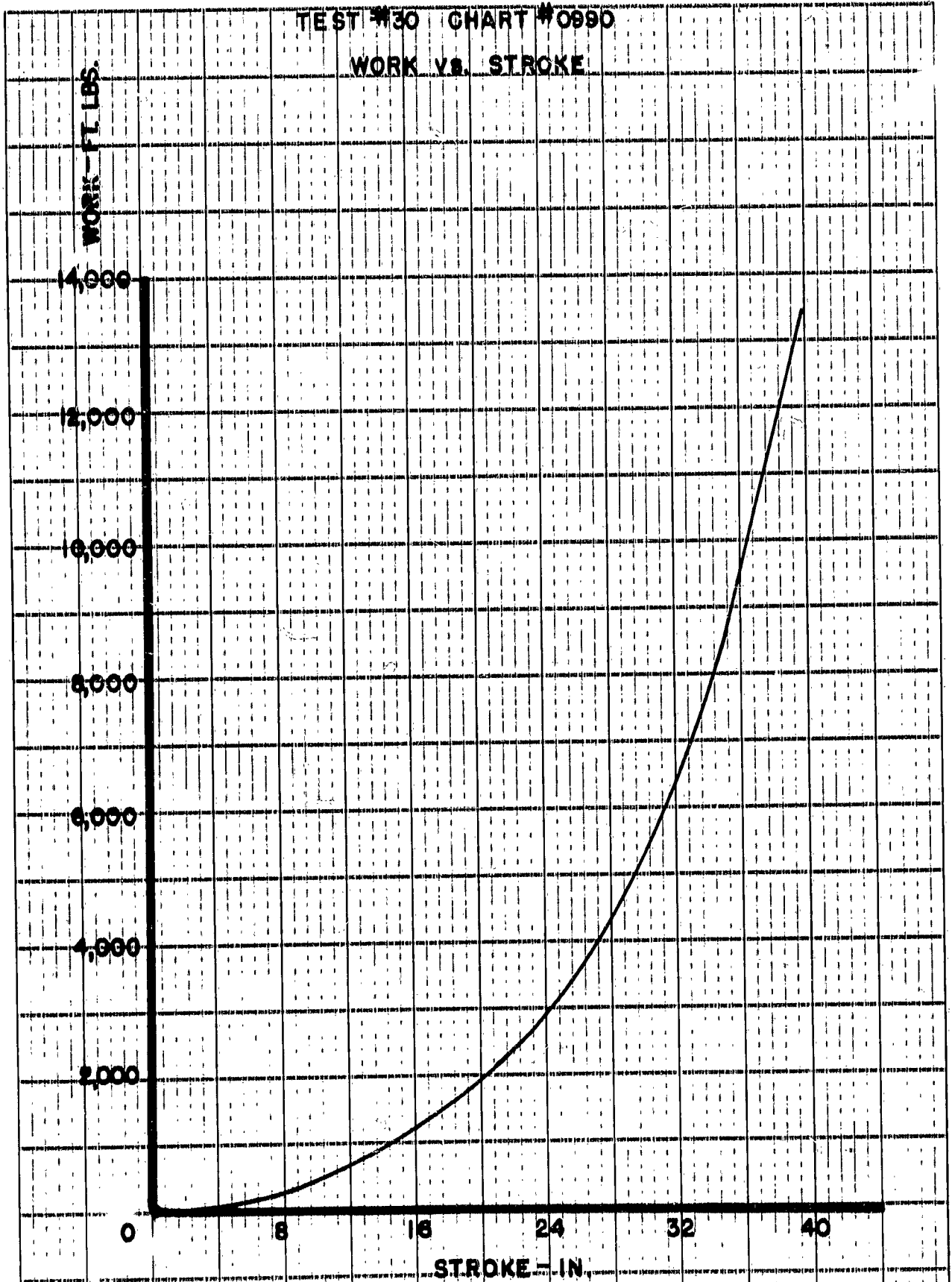
TEST #5 PARACHUTE DROP
24' PLATFORM 12 AIRBAGS
27.5 F.P.S. 1370 #/BAG
PRESSURE VS TIME

RIGHT FRONT AIRBAG

RIGHT MIDDLE AIRBAG

RIGHT REAR AIRBAG

PRESSURE—PSIG

TIME — SEC.

WADC TR 59-775

FIG. 88

118
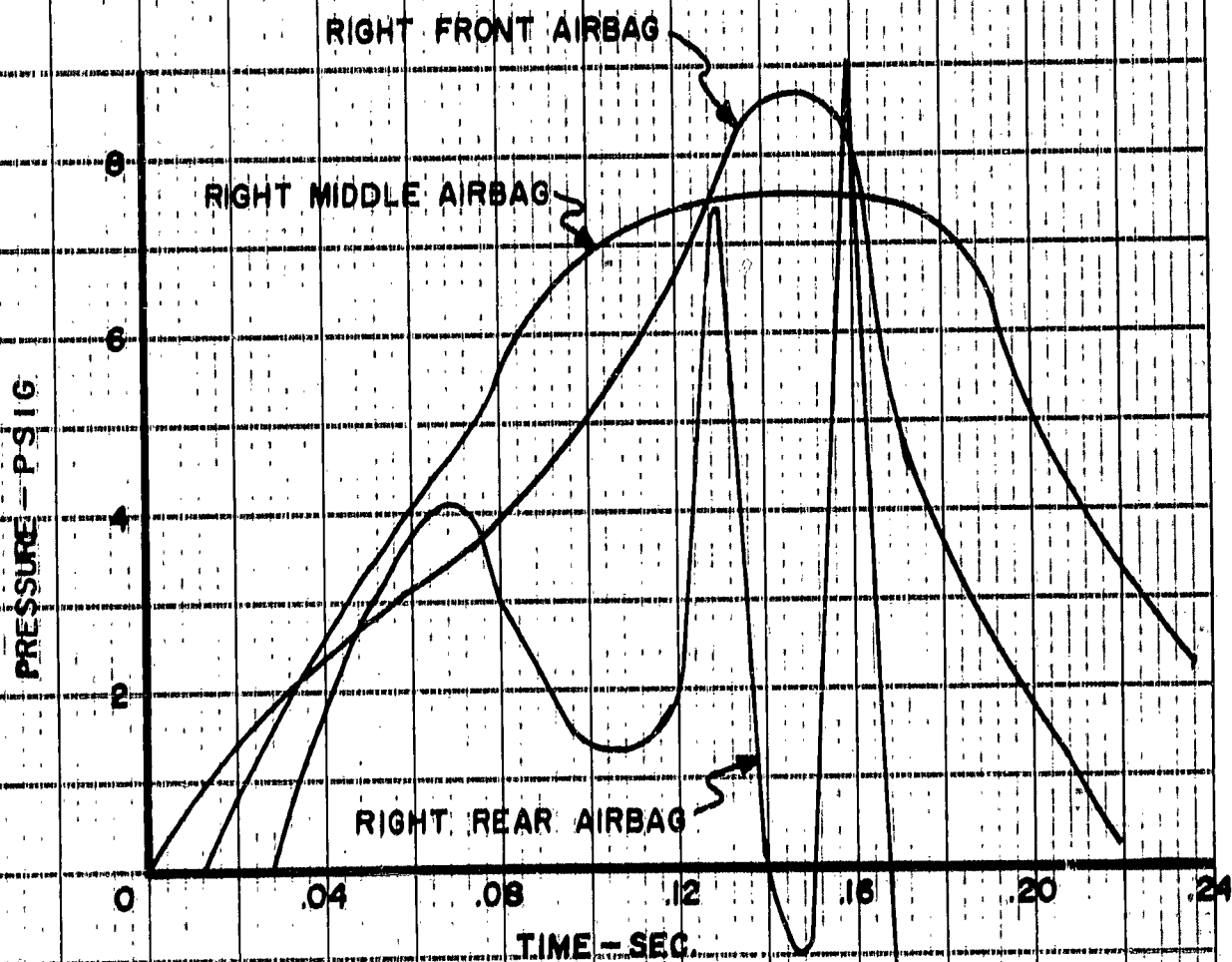
TEST # 6 PARACHUTE DROP
PRESSURE VS. TIME

LEFT FRONT AIRBAG

LEFT MIDDLE AIRBAG

LEFT REAR AIRBAG

PRESSURE — PSIG

TIME — SEC
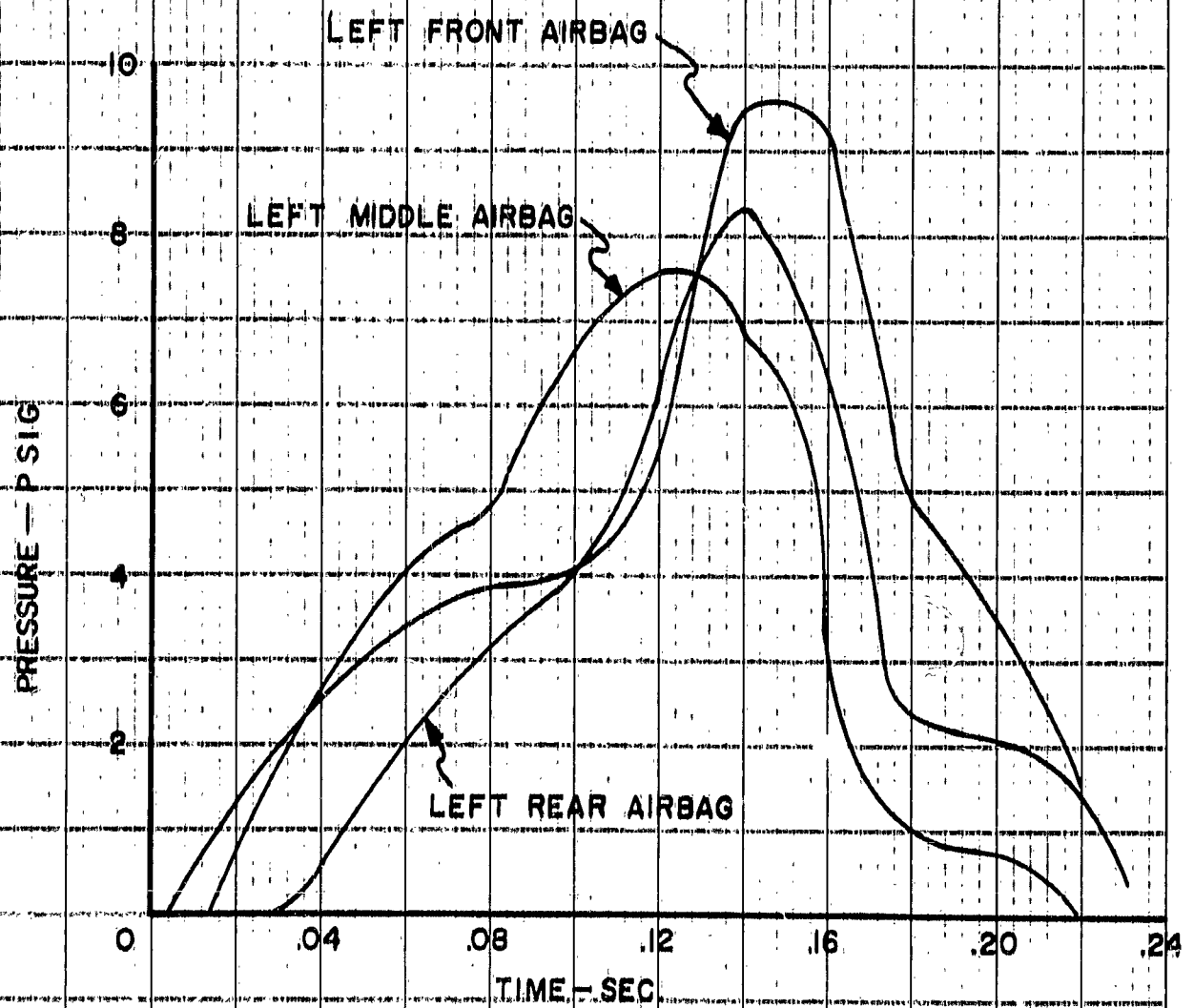
WADC TR 59-775   FIG. 89

119

TEST # 5   PARACHUTE DROP
DECELERATION, VELOCITY, STROKE VS. TIME

FIG. 90

120
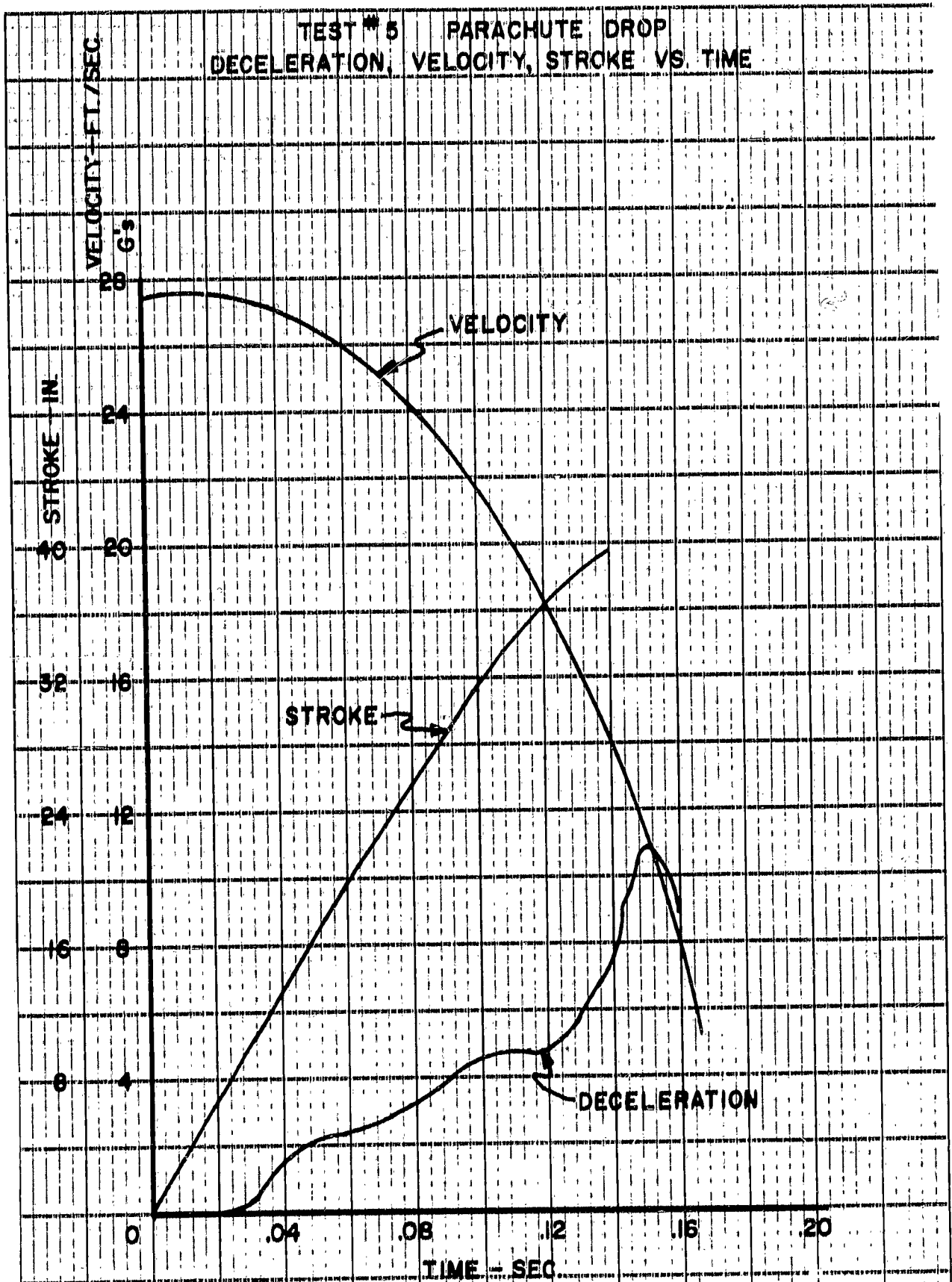
TEST # 5   PARACHUTE DROP
G's   VS STROKE

TEST #5   PARACHUTE DROP
WORK VS. STROKE

FIG. 92

TABLE I

SINGLE BAG TEST DATA   AIRBAG, 35" DIA. X 45'

TEST N°	MOVIE N°	RECORD N°	ORIFICE DIAMETER INCHES	PLUG DIAMETER INCHES	DROP TIME SEC.	IMPACT VELOCITY FT/SEC.	PLATFORM WEIGHT LBS	BLOWOUT PRESSURE PSIG	MAXIMUM PRESSURE PSIG	MAXIMUM DECEL (Y) G's	IMPACT DECEL (G's
17	2-9	0941	4.5	6	0.660	21.25	1385	5.00	7.30	4.15	7.52
19	2-10	0944	4.5	6	0.823	26.50	1385	3.93	10.35	6.92	13.55
21	2-11	0947	4.5	6	0.9275	29.85	1385	4.25	13.6	9.70	16.82
13	2-6	0937	5.0	6	0.675	21.70	1385	3.03	8.45	5.19	13.48
15	2-7	0939	5.0	6	0.820	26.40	1385	2.41	10.80	8.01	17.0
16	2-8	0940	5.0	6	0.930	29.95	1385	3.80	13.20	10.2	23.5
23	2-12	0960	5.0	6.5	0.668	21.50	1385	3.06	8.80	5.33	9.31
25	2-13	0963	5.0	6.5	0.835	26.90	1385	3.25	11.20	8.39	17.41
28	2-14	0986	5.5	6.5	0.675	21.70	1385	2.43	8.20	4.86	11.83
30	2-15	0990	5.5	6.5	0.830	26.70	1385	2.88	11.40	8.30	18.81
31	2-16	0991	5.5	6.5	0.945	30.40	1385	2.70	15.85	12.81	25.6
35	2-17	0996	5.0	6.5	0.968	31.15	1385	3.70	17.60	8.40	24.70
37	2-18	1011	?	?	0.677	21.80	1850	—	10.92	4.50	12.48
39	2-19	1013	?	?	0.850	27.35	1850	4.05	16.90	9.30	23.40

WADC TR 59-775

5" LG. CYLINDRICAL

T L (Y)	IMPACT DECEL (X) G's	IMPACT DECEL (Z) G's	PRESSURE (BOUNCE) PSIG	DECEL (Y) (BOUNCE) G's	RISE TIME TO MAX PR SEC.	REMARKS ON DROP (Observed from Films)
:	6.87	5.43	0.536	X	0.135	Bag lined up straight at ground contact. Bag buckled slightly at approx. 50% bag compression, causing one end of platform to hit ground first. Other end rebounded about 1½ ft. FAIR TEST
5	8.75	9.88	X	X	0.123	Approximately same conditions as above Test #17. FAIR TEST
2	13.3	9.88	1.16	0.19	0.113	Platform was noticed to fall unevenly; i.e. load was not balanced. Buckling occurred with one end of platform hitting ground first and other end rebounding. FAIR TEST
8	6.56	5.43	0.892	0.29	0.144	Bag lined up straight at ground contact. Bag buckled during compression causing one end of platform to hit ground and other end rebounded. FAIR TEST
)	5.63	7.41	0.892	0.09	0.127	Bag not completely filled with air, getting an uneven lining-up at ground contact. Bag buckled during compression causing platform to hit ground on one end. FAIR TEST
5	4.22	9.38	1.07	0.98	0.116	Bag not too well lined up at ground contact. Bag buckled during compression causing one end of platform to hit ground with other end rebounding. BAD TEST
	5.00	5.27	1.24	0.89	0.142	Platform did not fall evenly. Bag buckled during compression causing slight rebound. GOOD TEST
	12.00	8.42	3.25	3.00	0.121	Platform did not fall evenly. Bag buckled with one end of platform hitting the ground. FAIR TEST
3	5.58	1.191	1.53/0.81	1.12/0.31	0.147	Platform did not fall evenly. Bag buckled with one end of platform hitting the ground. FAIR TEST
	8.06	2.45	1.62	1.22	0.128	Platform did not fall evenly, causing buckle in bag during compression. One end of platform hit the ground. BAD TEST
;	7.44	2.45	1.80	2.56	0.108	Bag slanted under platform. Platform did not fall evenly. Platform hit into ground on one end. BAD TEST
0	2.48	2.75	1.82	2.43	0.120	Bag slanted under platform at ground contact. Platform leaned on angle before ground contact. Bad rebound. BAD TEST
8	6.18	6.31	1.23	0.19	0.143	Bag and platform fell evenly; however, bag buckled slightly during compression causing platform ground impact. FAIR TEST
0	7.41	6.06	1.78	1.27	0.115	Bag slanted during fall. Bag buckled causing platform to have ground impact. BAD TEST

2

TEST Nº	MOVIE Nº	RECORD Nº	ORIFICE DIAMETER INCHES	PLUG DIAMETER INCHES	DROP TIME - SECONDS	IMPACT VELOCITY FT/SEC.	PLATFORM WEIGHT LBS.	BLOWOUT PRESSURE - PSIG				MAXIMU
								P1	P2	P3	P4	P
7	REEL #1 7965	0674	4.5	6	0.84	27.05	1250	4.75	5.52	5.77	5.47	10.2
8	REEL #1 7965	0692	4.5	6	0.995	32.04	1250	5.28	2.13	5.86	5.83	9.81
9	REEL #1 7965	0693	4.5	6	0.735	23.67	1250	4.14	6.00	5.36	1.64	7.90
10	REEL #1 7965	0695	4.5	6	0.883	28.43	1350	4.61	5.24	5.85	3.34	12.2
11	REEL #1 7965	0719	4.5	6	0.733	23.60	1550	3.56	4.82	4.79	3.85	9.63
12	REEL #1 7965	0722	4.5	6	0.844	27.18	1550	5.66	4.26	4.31	3.96	10.37
13	REEL #1 7965	0723	4.5	6	0.940	30.27	1550	X	4.91	4.18	1.92	X
14	REEL #2 7965	0736	5.25	6.5	0.925	29.79	1550	3.35	4.02	4.21	4.84	10.47
15	REEL #2 7965	0737	5.25	6.5	0.905	29.14	1850	2.94	0.54	3.65	1.59	10.8
16	REEL #2 7965	0799	4.5	6	0.75	24.15	1850	3.86	4.82	4.29	4.38	10.15
17	REEL #2 7965	0803	4.5	6	0.818	26.43	1850	4.07	3.45	3.98	1.44	9.75
18	REEL #2 7965	0804	4.5	6	0.927	29.85	1350	2.44	2.15	1.84	1.73	10.15
*19	REEL #2 7965	0805	4.5	6	0.92	29.62	1350	1.62	1.21	0.77	0.72	10.15
*20	REEL #2 7965	0806	4.5	6	0.918	29.56	1350	1.42	1.38	0.77	0.72	10.25
21	REEL #2 7965	0833	5.25	6.5	0.909	29.27	1350	3.57	2.92	3.38	3.15	10.5
22	REEL #2 7965	0837	5.25	6	0.91	29.30	1350	3.57	X	3.50	2.37	10.0
23	REEL #2 7965	0856	5.0	6.5	0.925	29.79	1350	2.37	4.68	4.36	3.28	10.3
18-D	NONE	0830	4.5	6	0.905	29.4	1350	3.67	3.98	3.25	1.63	10.5
16-D	NONE	0800	4.5	6	0.74	23.83	1850	3.96	6.55	3.98	4.03	9.34
24-D	NONE	0857	5.0	6	0.915	29.46	1350	2.17	4.14	2.58	1.83	9.9
25	REEL #2 7965	0860	5.5	6.5	0.927	29.85	1350	1.86	2.71	2.42	1.61	10.2
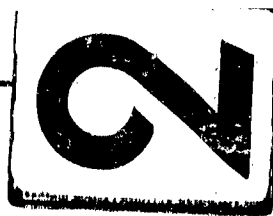
2

A. X 45" LG. CYLINDRICAL

P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	MAXIMUM DECEL.(Y) G's	IMPACT DECEL.(Y) G's	IMPACT DECEL.(X) G's	IMPACT DECEL.(Z) G's	DECEL.(Y) (BOUNCE) G's	
:SSURE·PSIG		RISE TIME TO MAXIMUM PRESSURE SEC.				PRESSURE (BOUNCE) PSIG									
13.9	12.6	0.13	0.128	0.126	0.12	1.41	2.98	0.77	1.69	12.3	12.3	1.02	1.08	3.76	Bags wer bounce o
17.43	15.24	0.112	X	0.114	0.105	1.15	4.42	2.19	4.52	12.1	19.55	1.24	1.98	4.27	Bags wer bounce,
14.03	11.08	0.15	X	0.136	0.132	X	X	X	X	7.45	9.91	X	X	X	Bags wer ground o
18.68	16.91	0.12	X	0.12	0.12	X	X	X	X	14.65	16.46	2.48	0.49	X	Bags spr Slight b
13.9	12.77	0.155	0.155	0.145	0.152	1.05	0.74	0.65	1.23	8.28	13.02	1.35	1.02	3.74	One bag bounce o
16.2	14.3	0.126	0.138	0.14	0.132	X	X	X	X	13.02	19.09	2.16	0.85	X	Bag spre impact,
17.1	X	X	0.127	0.126	X	X	X	X	X	12.20	24.60	2.71	1.71	X	Bags spr 1-1/2 fo platform
16.1	15.7	0.123	0.12	0.13	0.121	X	X	X	X	11.55	27.40	2.16	1.69	2.83	Bags wer of platf bounced.
15.9	16.4	0.13	0.13	0.125	0.125	X	2.32	3.81	5.15	10.68	28.60	2.97	1.18	4.96	Bags wer platform bounced.
15.8	14.7	0.16	X	0.142	0.142	X	X	1.76	0.29	8.60	17.3	1.23	0.93	3.60	Bags wer Bounce o platform
15.5	14.7	0.15	0.15	0.142	0.133	2.23	5.26	X	2.01	9.20	17.9	2.15	0.93	4.40	Bags prop end of p a.d bounc
15.1	14.1	0.125	0.125	0.11	0.107	3.66	5.68	X	2.59	14.20	24.6	4.01	1.39	9.40	Bags spr ne of and bounc
15.18	14.1	0.108	0.11	0.10	0.096	X	X	X	X	14.40	26.8	4.31	1.40	3.00	Bags un contact while ot
15.00	14.4	0.092	0.093	0.092	0.083	1.83	4.82	X	4.61	12.40	27.4	4.92	2.09	4.60	Bags un end of p bounced.
15.4	14.16	0.040	0.042	0.042	0.042	1.04	0.88	1.00	2.15	12.40	18.8	1.25	0.68	4.00	Bags were One end other enc
15.3	15.4	0.134	X	0.128	0.122	0.53	X	3.00	4.19	11.3	23.6	2.25	1.82	6.80	Two bags One end other enc
16.62	15.3	0.12	0.118	0.126	0.118	0.82	2.88	0.73	2.44	10.12	23.8	1.31	2.12	4.40	Bags not One end c and bounc
16.5	15.3	0.12	0.12	0.12	0.12	0.98	3.89	1.37	3.41	10.8	21.0	1.75	1.36	3.70	No movies
15.3	13.90	0.145	0.154	0.147	0.147	0.23	0.86	0.46	0.72	7.40	12.0	1.23	1.16	3.10	No movies
16.46	15.1	0.114	0.11	0.118	0.107	0.72	3.24	1.21	2.75	12.54	24.3	2.37	3.41	4.86	No movies
16.1	14.65	0.121	0.115	0.114	0.105	0.41	4.14	1.21	3.05	10.92	24.5	0.78	2.98	5.87	Bags not ground co on ground

(CE)PSIG	MAXIMUM DECEL.(Y) G's	IMPACT DECEL.(Y) G's	IMPACT DECEL.(X) G's	IMPACT DECEL.(Z) G's	DECEL.(Y) (BOUNCE) G's	REMARKS ON DROP FROM MOVIES
P4						
7	1.69	12.3	12.3	1.02	1.08	3.76	Bags were slanted at ground contact. Even bounce of 1/2 foot. GOOD TEST
9	4.52	12.1	19.55	1.24	1.98	4.27	Bags were slanted at ground contact. Uneven bounce, platform hitting on angle. BAD TEST
	X	7.45	9.91	X	X	X	Bags were properly lined under platform at ground contact. Even bounce of ½ ft. GOOD TEST
	X	14.65	16.46	2.48	0.49	X	Bags spread-eagled slightly at ground contact. Slight bounce of 1/2 foot. FAIR TEST
5	1.23	8.28	13.02	1.35	1.02	3.74	One bag out of line at ground contact. Even bounce of 1/2 foot. GOOD TEST
	X	13.02	19.09	2.16	0.85	X	Bag spread-eagled at ground contact. At ground impact, 1½ foot bounce. FAIR TEST
	X	12.20	24.60	2.71	1.71	X	Bags spread-eagled at ground contact. Approx. 1-1/2 foot bounce. Possible ground impact with platform. FAIR TEST
	X	11.55	27.40	2.16	1.69	2.83	Bags were slanted at ground contact. One end of platform remained in ground while other end bounced. BAD TEST
1	5.15	10.68	28.60	2.97	1.18	4.96	Bags were even at ground contact. One end of platform remained in ground while other end bounced. BAD TEST
	0.29	8.60	17.3	1.23	0.93	3.60	Bags were properly lined up at ground contact. Bounce of 1/2 foot possible. One corner of platform had ground impact. GOOD TEST
	2.01	9.20	17.9	2.15	0.93	4.40	Bags properly lined up at ground contact. One end of platform remained in ground while other end bounced. BAD TEST
	2.59	14.20	24.6	4.01	1.39	9.40	Bags spread-eagled at ground contact. One corner of platform remained in ground while other end bounced. BAD TEST
	X	14.40	26.8	4.31	1.40	3.00	Bags unevenly lined up under platform at ground contact. One end of platform dug into ground while other end bounced. BAD TEST
	4.61	12.40	27.4	4.92	2.09	4.60	Bags unevenly lined up at ground contact. One end of platform dug into ground while other end bounced. BAD TEST
	2.15	12.40	18.8	1.25	0.68	4.00	Bags were slightly slanted at ground contact. One end of platform remained in ground while other end bounced approx. 1-1/2 feet. FAIR TEST
0	4.19	11.3	23.6	2.25	1.82	6.80	Two bags slanted outward before ground contact. One end of platform remained in ground while other end bounced slightly. FAIR TEST
3	2.44	10.12	23.8	1.31	2.12	4.40	Bags not lined up properly at ground contact. One end of platform remained on ground. Other end bounced. FAIR TEST
7	3.41	10.8	21.0	1.75	1.36	3.70	No movies.
6	0.72	7.40	12.0	1.23	1.16	3.10	No movies.
	2.75	12.54	24.3	2.37	3.41	4.86	No movies.
	3.05	10.92	24.5	0.78	2.98	5.87	Bags not lined up properly under platform at ground contact. One end of platform remained on ground. Other end bounced. BAD TEST

3

TABLE III

EFFICIENCY RESULTS OF DROP TESTS

	Multi-Bag Tests				Single Bag Tests			
Test	E_1	E_2	E_3	E_4	Test	E_1	E_2	E_4
7	96	105.8	57.2	30.1	17	100	314	75.1	17.51
8	70.4	107.5	56.2	51.4	19	85	188	52.3	27.25
9	96	174.5	77	23.0	21	90.6	134	48.1	34.5
10	98.7	88.7	53.6	32.2	13	95.6	250	59	18.24
11	60	157	43.2	22.9	15	68.4	162	36.2	27.1
12	55.6	100	31.5	30.4	16	73.4	127.5	37.4	34.8
13	58.8	106.6	42.2	37.7	23	99.6	244	58.9	16.0
14	61	112.6	45.1	36.5	25	95.6	155	49.9	28.0
15	49.6	122	38.4	34.9	28	71.9	268	47.4	18.24
16	68.1	151	48.9	23.9	30	66.9	156.6	34.9	27.6
17	60.7	141.2	46.9	28.3	31		101.5		32.85
18	69.7	91.5	42.1	36.6	35	69.6	154.8	45.7	37.7
19	68	90.2	44.9	41.4	37	88.4	289	63.1	18.43
20	55.7	105.	49.2	44.3	39		140		28.8
21	54.9	105	36.8	35.3					
22	49.4	115	36.4	35.38					
23	67.7	128.5	57.3	36.5					
18-D	62.5	120.5	48.5	35.5					
16-D	66	175.8	54	23.4					
24-D	82	103.8	54.8	35.7					
25	77.6	119	60.5	36.6					
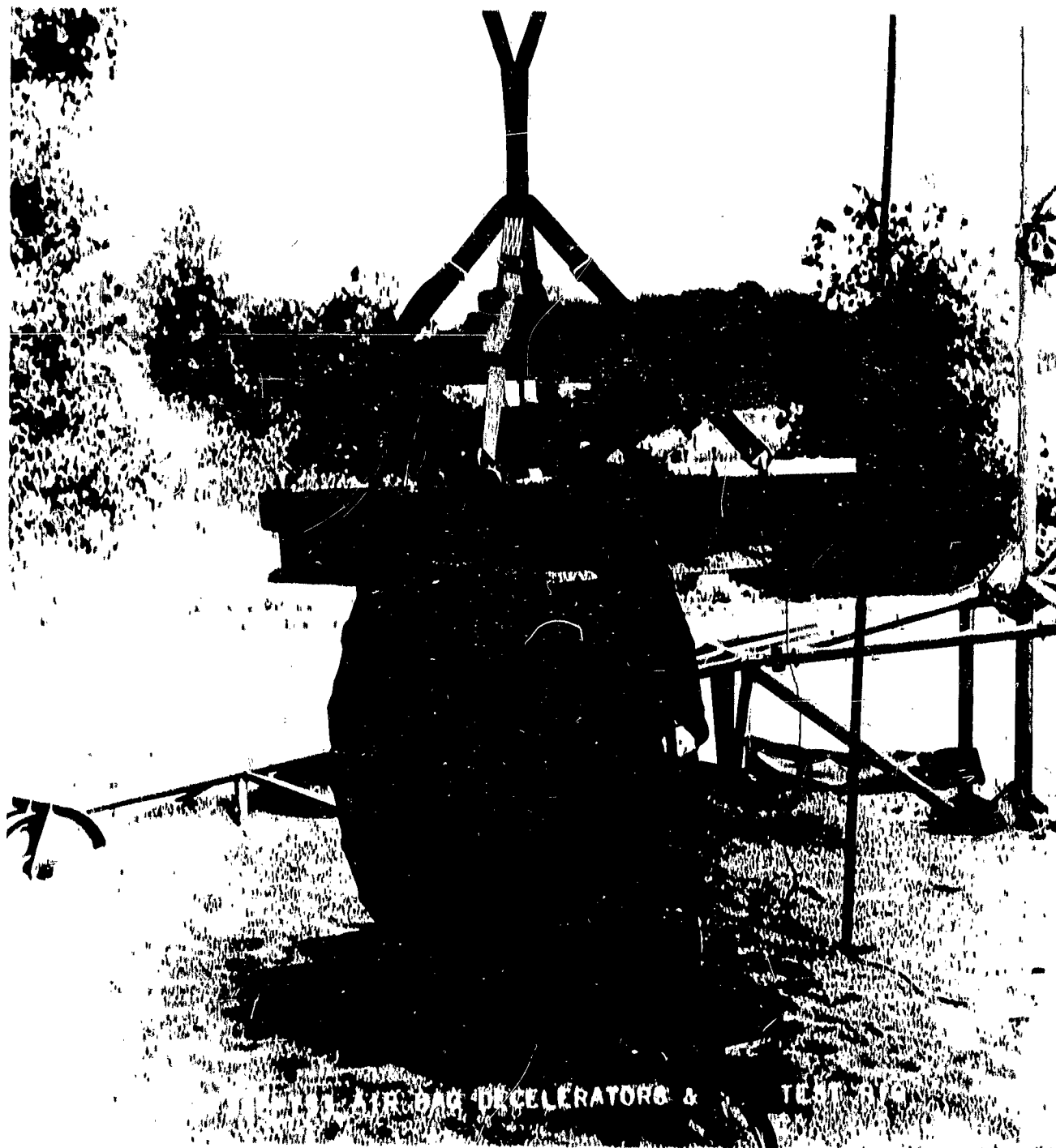
Barrel-shaped airbag mounted in free-fall test rig.

FIG. 93

Cylindrical Airbag with the variable diameter orifice and blow out bung.
FIG.   94

Cylindrical shaped airbags mounted in free-fall-test rig.

FIG. 95